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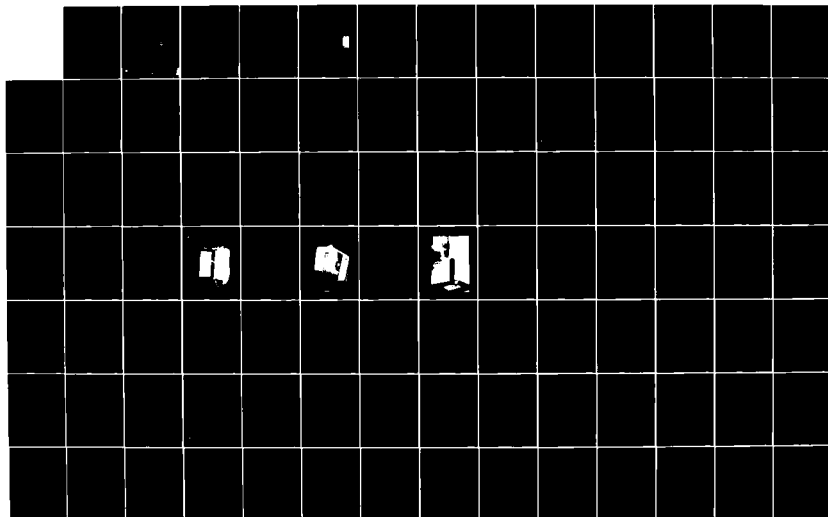
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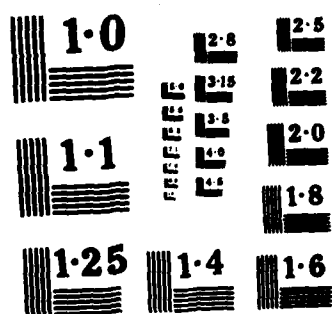
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INTRODUCTION

Public concern about radiation safety has increased in recent years. Both the news media and congressional hearings in Washington, D.C., have focused attention on the potential hazards of ionizing radiation. The result is that governmental laws, regulations, and guidelines have indicated a need for an effective, inexpensive, and acceptable method to assure that dental radiographic quality is maintained with minimum patient exposure. To achieve this objective, some form of quality assurance testing must be used.

Quality assurance may be defined as a series of tests performed to determine whether x-ray machines and/or processing procedures are functioning properly. It is well recognized that inconsistencies in processing techniques are a major problem in dental radiology and provide a much greater source of variability than x-ray machine inconsistencies. For this reason, many different forms of quality assurance tests have been developed to monitor processing activity while few tests have been constructed for x-ray equipment. Various visual, chemical, instrumental, and mathematical methods have been devised for film processing. Tests indicating gross errors have been largely based on guesswork or

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THE ACCURACY OF AN ALUMINUM STEPWEDGE TEST
FOR MACHINE AND FILM PROCESSOR QUALITY
ASSURANCE IN DENTAL RADIOLOGY

by

ROBERT M. BLOXOM, D.D.S.

MAJOR, USAF, DC

A THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Dentistry
in the Department of Dental Radiology in the
Graduate School, University of Alabama
in Birmingham

BIRMINGHAM, ALABAMA

1984

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INTRODUCTION

Public concern about radiation safety has increased in recent years. Both the news media and congressional hearings in Washington, D.C., have focused attention on the potential hazards of ionizing radiation. The result is that governmental laws, regulations, and guidelines have indicated a need for an effective, inexpensive, and acceptable method to assure that dental radiographic quality is maintained with minimum patient exposure. To achieve this objective, some form of quality assurance testing must be used.

Quality assurance may be defined as a series of tests performed to determine whether x-ray machines and/or processing procedures are functioning properly. It is well recognized that inconsistencies in processing techniques are a major problem in dental radiology and provide a much greater source of variability than x-ray machine inconsistencies. For this reason, many different forms of quality assurance tests have been developed to monitor processing activity while few tests have been constructed for x-ray equipment. Various visual, chemical, instrumental, and mathematical methods have been devised for film processing. Tests indicating gross errors have been largely based on guesswork or

professional experience. Tests of greater accuracy have been found to be too complex, costly, or time consuming to be acceptable for use by general dental practitioners. For a quality assurance test to be practical, it must be both inexpensive and simple to use.

Recent attempts at an acceptable dental quality assurance test using an aluminum stepwedge in lieu of sophisticated instrumentation have either been limited in scope, resulting in failure for various reasons, or have had inadequate documentation of the effectiveness of the test through measurement of the many variables involved. Consequently, there is no single proven quality assurance test available in dentistry that will detect deficiencies of both machine and processing activity and at the same time have the qualities necessary to be potentially acceptable to the dental profession. Simplified quality assurance tests are available that will detect machine and processing deficiencies, but unfortunately more than one test must be performed. A single test to accomplish both purposes would clearly be advantageous.

Purpose

The purpose of this study is to determine the effectiveness of an aluminum stepwedge in a simplified quality assurance test to detect both x-ray exposure changes and

processing solution activity prior to loss of clinical diagnostic radiographic quality.

LITERATURE REVIEW

The review of the literature will be presented in terms of the evolvement of quality assurance requirements, quality assurance in medical radiography, and quality assurance in dental radiography.

The Evolvement of Quality Assurance Requirements

Early in the development of radiography many attempts were made to control patient x-ray exposure. In recent years statements from the President of the United States and reports from the Food and Drug Administration have indicated that both the need and impetus for research and development of a quality assurance program acceptable to the dental profession are, at this point in time, clearly evident.

The Food and Drug Administration announced in the Federal Register (1976) that proposed recommendations for quality assurance programs in diagnostic x-ray facilities were to be developed. The proposed recommendations were intended to encourage voluntary development of facility-based quality assurance programs. Activities were designed to make the radiology community aware of quality assurance. The type and number of quality assurance actions recommended and the

frequency of the application of a particular action would depend on such factors as the size of the facility, the type and number of diagnostic procedures performed, and the components of the x-ray system being considered. In the experience of the Bureau of Radiological Health, voluntary facility-based programs are the most promising way to get consistent nationwide production of high-quality diagnostic radiographs at minimum cost and minimum patient exposure.

Quality assurance recommendations were also approved by the President of the United States and published in the Federal Register (1978). The document stated that x-ray facilities should have quality assurance programs designed to produce radiographs that satisfy diagnostic requirements with minimal patient exposure, and that techniques appropriate to the equipment and materials available should be used to maintain exposure as low as is reasonably achievable without loss of requisite diagnostic information.

A conference of the National Center for Health Care Technology (1981), the purpose of which was to promote the effective, safe, and cost effective use of high-quality dental radiographs, concluded that quality assurance could improve radiologic practices, but lack of motivation was identified as a primary barrier to implementation of such a program, and that further research and development were required for an acceptable system. The conference further stated that quality assurance programs compatible with the

normal pattern of daily activities of patient care in dental offices must be developed.

Santangelo (1982) stated that quality assurance was a rapidly evolving trend in the health professions generally. However, its specific application to dental radiology is somewhat elusive. It must provide for quality control mechanisms and techniques to monitor the various components of the total x-ray system. He also stated that the American Dental Association Commission on Dental Accreditation expects institutions to provide on-going programs related to monitoring equipment, darkrooms, processing solutions, and the use of ionizing radiation. Santangelo indicted that the commission assumed that the dental radiology faculties would have not only the responsibility, but also the authority for developing, implementing, monitoring, controlling, and enforcing radiation policies throughout the institution.

Graham and Santangelo (1982) stated that mounting public interest in radiation effects has prompted some legislators to introduce bills that call for the establishment of minimum federal standards for the accreditation of programs that teach personnel to use x-ray equipment, and for licensing or credentialing users of such equipment. In 1981, the US. Congress enacted into law the Consumer-Patient Radiation Health and Safety Act. The legislation mandated that the Secretary of the Department of Health and Human Services

develop standards to be used in accrediting and credentialing or licensing of persons who administer radiographic procedures.

Quality Assurance in Medical Radiography

There are many variables involved in the production of a diagnostic radiograph. Since any practical quality assurance test is unable to measure each of the many variables involved, any acceptable test can only be directed toward the most important variables. Deficiencies resulting from the numerous variables may be basically categorized as either x-ray machine or processing deficiencies.

Wilsey (1925) recognized the problems of film development in the radiographic process. He indicated that almost any sort of development will bring out an image from a properly exposed film. The resulting radiograph could be of some use, but may not be the best that can be produced. The radiograph may thus fail to provide some valuable information which might otherwise have been obtained with more suitable film processing. He studied the phenomena of development with an exposing machine, or sensitometer, that exposed film strips equally. Progress of development was thereby observed on these films with a photometer that read the radiographic densities. Wilsey's work took into account only the film development aspect of the radiographic process.

Wilsey also described a simple test for estimating the degree of exhaustion of a developing solution. The test was based on the fact that the time of development bears a definite ratio to the time required for the image to appear after the film is first immersed in the developer. This ratio was called the Watkins factor. The time of appearance of the image was multiplied by this factor to find the correct time of development.

The film processing fault arising from continuing the same fixed development time throughout the life of the developer was observed by Chamberlain and Newell (1930). They stated that the obvious cure was to increase the development time as the developer activity decreases. They considered a method of keeping a running account of the number of films developed. After 107 films were developed in a 5-gallon tank, it required 6 minutes instead of 5 for proper development. After 48 more films were developed, an increase to 7 minutes was required. They stated that the Eastman Kodak Company was at that time recommending this method of control.

Chamberlain and Newell also carried development control one step further by suggesting the use of a "copper staircase" as a contrast scale. Copper sheets of 0.23 mm thickness were stacked in increments of from 1 to 7 sheets to form a stepwedge. This stepwedge was laid over films which were subsequently exposed and processed daily. If a step of the radiograph was 1 step lighter than the same step on the

standard radiograph, developing time was increased 15%; if it was 1 step too dark, developing time was decreased 15%.

Henny (1934) recognized that Chamberlain and Newell's "copper staircase" quality control method was exact, but observed that their test films were made with the aid of an accurately controlled therapy machine not available to many radiologists. Henny described a method for determining the potency of the x-ray developer in which the test films were exposed with a radiographic machine, to which most radiologists had access. Since the radiographic machine was not equipped with instruments to ensure constancy of output at different times, special precautions were necessary so that the process of calibrating the developer could be carried over from one test film to the next. A fresh 8 by 10 inch film was exposed under an aluminum stepladder made of aluminum sheets 1 mm thick, 10 inches wide, and arranged in a staircase running from 1 to 7 thicknesses. An inch was cut off one end of the film and developed in a 1-day-old developer. This strip was set aside as the "standard strip" with which subsequent calibration strips were compared. One to 3 days later, depending upon the size of the tank in relation to the volume of work, another strip was cut from the film, developed, and compared to the "standard strip." If it was found to be 1 step lighter than the "standard strip," the developing time was increased by 0.5 minutes; if 2 steps lighter than the "standard strip," development time was increased 1 whole minute. The process was repeated with an

increase in development time of 0.5 minutes for each step density difference until developing time reached 8 or 9 minutes. The method was not expensive and could be used by most radiologists.

Burger (1949) described a method for quality control of radiographs of the thorax. Control of contrast qualities was maintained by means of a quality control phantom small enough to be placed at the upper end of the film near the neck. The phantom consisted of 2 sets of 5 aluminum steps from 4 to 8 mm and 9 to 13 mm. On each step 5 balls of bakelite with a diameter of 4.0, 2.8, 2.0, 1.4, and 1.0 mm, respectively, were attached. At one side a set of 5 steps of copper (thicknesses 0.2, 0.3, 0.4, 0.5, and 0.6 mm) was added in order to have further control of contrast qualities. At the other end a lead strip was placed as a test of darkroom technique and to estimate the fog. Certain areas of the lung were compared to one of the aluminum steps with equal density. The number of bakelite balls visible gave an indication about the quality and resolving power of each radiograph.

Seemann and Roth (1960) stated that copper stepwedges fastened to chest films could occupy an area which could be kept clear. For general use, however, and particularly in radiography of the abdomen, this would lead to the risk of having the patients' body overlies the wedge. Even if the wedge were free of overlying tissue, scattered radiation from patients of various sizes could penetrate it and invalidate the results. It therefore seemed desirable to use a

stepped wedge phantom whose radiographic image would be affected by scattered radiation in much the same manner as that of a patient. A stepped wedge made of a homogenous tissue-like substance appeared to be the logical choice. As a result, a Plexiglas wedge was designed for exposure techniques commonly used for the pelvic region. In the interest of simplicity, the Plexiglas phantom contained no bone-like structures (such as ground bone dispersed homogenously in a plastic and formed into small stepped wedges). Considering the fact that the practical usefulness of a device of this kind may depend as much on convenience as on completeness of details, they decided to make the simpler phantom, without bone, which might be used in a busy laboratory, rather than one which would be discarded for lack of time to evaluate.

The problems of quality control involving the use of a sensitometer and densitometer were indicated by Chanin and Barnes (1954). They stated that determination of developing solution activity requires at least 1 hour and entails film exposure in a sensitometer, processing the film, measurement of the radiographic density with a densitometer, and plotting density curves. During the 1 hour of the test the activity of the developer changed. They also stated that costly and complicated equipment was necessary and that trained personnel were needed. It was evident that only the largest x-ray departments could supply the necessary equipment and personnel. Therefore, they proposed a chemical method for determining the activity of developer solutions.

The test involved the use of burettes, pipettes, flasks, indicator solutions, titrations, and computations.

Nichols and Moseley (1957) stated that although chemical methods of developer control seemed attractive they only tested the oxidation-reduction potential of the developer. The complicated interaction of other salts in the developer could not be determined by simple chemical methods that had been proposed. They proposed a sensitometric method of testing darkroom function, by using a sensitometer and densitometer.

The need for a relatively simple and inexpensive method for periodically checking the efficiency of film processing procedures was indicated by Trout, Kelley, and Anderson (1971). They proposed the use of a standard light source to expose the film to remove the variable associated with erratic x-ray machine functions. They duplicated Nichols and Moseley's system using other parts to replace some that were no longer available. In addition, they improved Nichols and Moseley's system by using a voltage stabilizer to counteract line voltage fluctuations, and lengthened the exposure time to reduce timing errors with short exposures.

Faix, Van Tuinen, and Kereiakes (1973) addressed the problem of quality control in the use of automatic processing. They stated that operational variability of automatic processing units was a contributing factor to the production of defective quality radiographs and had not been reported in the literature. They observed that a practical, easy to

use method to maintain quality control of film processing was needed. They suggested that the use of a stepwedge with visual comparisons of the resulting densities being the ideal approach. However, they recognized that there were inherent problems related to exposure of the stepwedge with an x-ray machine. For example, each succeeding step of the stepwedge altered the quality of the radiation received, and variations in line voltages also complicated the use of a stepwedge. Therefore, they recommended using a sensitometer and densitometer to get an accurate evaluation of changes in film processing. An important concept mentioned was that the instrumentation necessary depended upon the amount of precision required.

As stated 39 years earlier by Wilsey (1934), a precision of 5% or better in photographic photometry of roentgen rays was usually required. He stated that photographic materials were intended primarily for recording images for visual inspection. They were not designed for the measurement or comparison of radiation intensities, although they could be useful for that purpose if proper techniques were followed. He stated that it is difficult to be sure of the uniformity of the activity of the developer, which may be affected by variations in the quality of chemicals, the procedure of mixing, age of the solution, etc. Therefore, it seemed almost impossible to specify and realize standard conditions of development with sufficient precision for photometric purposes. Sensitivity variations of no importance

in practical radiology could be quite objectionable in intensity measurements. Even the sensitivity variations over the area of a single film may exceed the permissible error of measurement of radiation intensity.

Seemann and Roth (1960) designed a stepwedge in an attempt to overcome the limitations of varying thicknesses of a stepped wedge, altering in different amounts the quality of radiation received by the film. They improved the design by making an aluminum stepwedge symmetrical about the middle step to reduce the effect of non-uniform scatter from various thicknesses of the wedge. In order to make the densities even more uniform they added a thin copper sheet .053 mm thick to the base of the symmetrical stepwedge to act as a filter for removing scatter radiation.

Wilsey (1925), Nichols and Moseley (1957), Cronin (1978), Trout, Kelley, and Anderson (1971), and Faix, Van Tuinen, and Kereiakes (1973) all used a sensitometer in quality control. In an attempt to eliminate the need for a sensitometer in quality control of processing solutions, Polanski and Smith (1968) used pre-exposed control film strips. They found that pre-exposed film strips that were aged for 3 months had faded latent images and were not as sensitive to changes in developer activity as were images on freshly exposed film strips. Having previously ruled out using x-rays for exposing fresh test films, they concluded that the use of a sensitometer was the best method of monitoring processing solution activity, and that the use of pre-exposed films, as

well as non-screen films exposed with an aluminum stepwedge to x-rays, were almost useless in film processing control. Polanski and Smith did not define the magnitude of the processing errors they intended to detect.

The problem of latent image instability and fading, as encountered by Polanski and Smith, had been investigated 14 years earlier by McLaughlin and Ehrlich (1954). They studied latent image fading of 6 different films with storage time and found variations in the amount of fading due to many variables. Time, emulsion type, atmospheric chemicals (O_2), and physical factors--such as temperature, grain size, humidity, and the type of processing--were all involved in the fading process. In addition, the relative importance of chemical and physical causitive agents probably differed for various types of emulsions. McLaughlin and Ehrlich studied latent image fading during only the first 6 days after exposure.

Heat and humidity are the 2 factors that most often affect the aging of film (Eastman Kodak Company, 1984). These elements can be controlled to some degree by protecting film from heat and sealing it in vapor-resistant containers. Other environmental factors also contribute to changes with age.

The effects of processing in photographic monitoring were investigated by Corney (1952). He stated that the most important requirement in measurements of radiation by means

of photography is the processing of the exposed film. He measured the percent error in dosage measurement using non screen film with various development times, development temperatures, and the chemical exhaustion of developer. He found that a 2-minute reduction in development time (from a 5-minute optimum) produced an error of approximately 30% in dosage measurement, while a 2-minute increase produced approximately a 20% error. A 4°F drop in developer temperature from a 68°F optimum produced approximately 20% error in dosage measurement, while a 4°F increase produced approximately a 10% error. A 20% error in dosage measurement occurred with approximately 6,000 square inches per gallon of processed film. All 3 experiments were based upon films exposed to give density 1 when properly processed.

Products for use in diagnostic radiology quality assurance were listed in a catalog published by the Bureau of Radiological Health (1977). Nine sensitometers were listed and ranged in price from \$145.00 to \$1600.00. The average 1977 price of the 9 sensitometers was \$582.00.

Lorimer (1974) devised a method to make a simplified sensitometer from a wooden box containing an electronic flash. Readings from test strips were recorded by a densitometer and characteristic curves were plotted to obtain contrast, fog level, maximum density, and emulsion speed. Any changes in these curves with subsequent strips would measure some alteration in processing. She stated that it

was not always necessary to plot a curve because gross faults could be seen by visual examination.

Dobrin et al., (1974) found automatic processor reliability to be questionable. Since the film processor is a vital link in the production of high quality radiographs, some form of quality control must be used. They stated that the minimum equipment necessary for a monitoring program includes an accurate thermometer, a densitometer, and a sensitometer. Cronin (1978) also stated that the best approach to quality assurance programs is with the frequent use of sensitometry because the processing operation must be evaluated more often than the output of the x-ray equipment.

McLemore (1981) stated that the accuracy of the peak kilovolt set on the control panel can have a dramatic effect on the overall quality of the finished radiograph. She also stated that a variation in the peak kilovolt reading will result in a greater change on the radiograph than an equal variation in target-film distance, exposure time, or tube current setting. McLemore described one of the most widely used calibration instruments, the Wisconsin peak kilovoltage test cassette, which is made up of 5 copper step wedges incorporated in a modified 8 by 10 inch cassette. Pairs of circular density spots are matched to indicate the kilovolt peak. An accuracy of plus or minus 4 kVp can be achieved with eye matching of the density steps and an accuracy of plus or minus 2 kVp can be achieved with densitometric matching of the density steps.

Quality Assurance in Dental Radiography

A few weeks after Roentgen's announcement of the discovery of x-rays, no meters had yet been devised for determining the quality or quantity of the x-ray beam produced (Preece, 1969). The accepted method of estimating the x-ray beam quantity and quality was for the operator to hold a fluoroscope in his right hand and place his left hand in front of it, start the machine, and adjust the rheostat until the bones of the hand showed clearly. This was one of the earliest quality assurance methods and led to the deaths of many early radiologists. Eventually the human hand was replaced by the osteoscope, which consisted of a skeleton's hand, held by the operator whose hand was enclosed in a protective shield.

Price (1901) stated that there had never been any standard adopted for expressing x-rays of various qualities, but he stated that Roentgen made a radiometer of platinum foil .0026 mm thick with 15 circular windows. In each window he placed 1 additional number of discs of aluminum foil 0.0299 mm thick. X-rays passing through this radiometer indicated the penetrating power of the beam by the number of windows in which the absorbability was the same in the platinum and aluminum. Price stated that Roentgen's idea was excellent but, since dental radiography required x-rays of higher penetrability, Roentgen's radiometer was hard to read. He had used an aluminum wedge 8 inches long and 1 inch wide, built up

with layers of .65 mm thickness. Each step was numbered with lead numbers. This wedge was used with the fluoroscope to judge the penetration of x-rays with great accuracy, but its size was a great disadvantage. Price therefore recommended a radiometer which was just as accurate, while being very cheap and easy to secure. It was made of pure copper rolled accurately to 0.1 mm thickness, and built up in 12 steps. Each step was flooded with rubber cement or glue, then wrapped with thin strong paper, and allowed to dry. On one end was cut some small gauges 1/8 inch wide using a pair of shears. The radiometer was laid on the end of the film to extend beyond the teeth when radiographing the patient or when using the fluoroscope. The information obtained indicated the proper x-rays to be used.

Two different methods were described by MacKee (1914) in estimating both the quality and quantity of an x-ray beam. He stated that in estimating the quality (hardness or penetration) of an x-ray beam, some sort of penetrometer should be used. There were several types on the market at that time, but he found nothing superior to the Benoist radiochronometer. This instrument was composed of a central disc of silver surrounded by 12 discs of aluminum arranged like numerals on the face of a clock. These sectors ranged from 1 to 12 mm in thickness. The value of the Benoist radiochronometer was based on the silver varying but little with an increase in the hardness of the x-rays, whereas the transparency of the aluminum increased greatly with increased

penetrating power of the x-ray beam. When a radiograph of this instrument was made, the shadow of one of the aluminum sectors would correspond in density with that of the silver disc thereby estimating the degree of hardness of the beam. The aluminum discs were numbered from 1 to 12, and if number 5 matched the silver disc density, then the beam was said to be a "number 5 Benoist." MacKee also described an instrument used to estimate the quantity of rays, the Holzknect radiometer. Its function was based upon the action of x-rays on a platino-cyanid of barium, which was a bright green color when freshly prepared. When exposed to x-rays it gradually assumed a yellowish brown color, and finally, a reddish brown color. By exposing a tablet and comparing it to a standard color, the radiometer gave an idea of the quantity of x-rays which had been delivered. That quantity was then related to the quantity of ray necessary to produce an erythematous reaction of the skin of the face of a middle-aged male. Use of the Holzknect radiometer determined the quantity of x-rays below the erythematous dose which, at that time, was considered to be a safe dose.

A more technical method of dental quality control called "sensitometry" was described by Wilsey (1930). A series of known exposures was impressed upon dental film by a specially designed machine called a sensitometer. Strips of film were then developed, and characteristic curves were obtained indicating the various characteristics of dental

film. Developing procedures could then be optimized to yield the best quality radiographs.

A penetrometer designed to fit on a dental film was described by Austin (1934). He used a rectangular bar of duralumin 1 inch long and graduated with segments varying from 1 to 5 mm in thickness. He found that too little of the metal was penetrated by the x-ray beam to be useful in recording the photographic effect. He then made another penetrometer the same size using magnesium, which has a specific gravity about half that of duralumin. Variations in exposure, development time, and target-film distance could readily be shown by comparison of photographic images of the penetrometer on 2 films.

A clear understanding of photographic effects of ionizing radiations was essential for the satisfactory formulation of a film monitoring program (Cowing and Spalding, 1949). They stated that quantitative errors seldom exceed 5% when film of the same type and emulsion numbers are simultaneously developed, but a difference as great as 30% should be expected if the films were developed at different times. This error could rise to 50% or more if films of different emulsion numbers were used.

Price (1973) described a sensitometric method for use in dental radiology to reduce errors caused by variations in emulsion and processing. A brass strip 3 mm thick, 25 mm wide and 50 cm long was supported on nylon runners. It was propelled by an electric motor by means of a silk thread

attached to one end of the brass strip and connected to the motor. By varying the speed of the motor, the strip was made to progressively uncover a film during exposure. This enabled values of density to be plotted against length of exposure in the form of a sensitometric curve. Processing techniques could then be compared and controlled.

Wuehrmann, Jamison, and Manson-Hing (1963) found a wide variability in processing techniques in a study of 195 dental offices and clinics. Gibbs, Crabtree, and Johnson (1977) also found that the incidence of inadequate processing techniques was surprisingly high and was a major cause of unnecessary patient exposure.

Pentel and Hyman (1967) stated that developer activity was one of the most prevalent factors in the production of an unsatisfactory clinical radiograph. They proposed a method to detect developer changes that used a series of 4 previously exposed reference films. Pre-exposed test films were periodically developed and compared with the reference films to assess developer changes. They stated that production of the standard reference films was completely dependent on the availability of a densitometer. They also stated that the pre-exposed test films could lose some of their effect with time, and that, although data on this matter were incomplete, test films should be used within 3 months.

Buchholz (1975) found that considerable output variations exist in dental x-ray generators when operated with the same kilovoltage and milliamperage factors. He stated

that dentists using the recommended exposure factors may find radiographs of poor density and must often resort to trial and error methods of establishing proper exposure, which is not consistent with ideal radiation health concepts. Failure to achieve diagnostically acceptable radiographs because of machine inaccuracy was frustrating and discouraging to the practitioner.

Spectroline[™] marketed a dental x-ray quality control system used to analyze x-ray exposure to dental films. It consisted of a 2-step density stepwedge with an area that blocked x-rays, and was used in combination with a control film standard. If step densities were correctly processed but were too light relative to the standard film density, then exposure time was increased. Conversely, if step densities were too dark, exposure time was decreased. The area of the stepwedge blocked from x-rays was clear when properly processed. If the clear step was fogged, an 11-point checklist was used as an aid in locating the fog source. The test was based on the assumption that correct processing procedures were followed.

Brown, Winkworth, Anderson, and Jarman, (1973) stated that without quality control in film processing, inadequate radiographs can result, and that inconsistencies in processing techniques are recognized as a major problem in dental radiography. They therefore monitored processing solution activity with the use of an aluminum stepwedge and densitometric readings to determine the number of satisfactory

intraoral radiographs that could be produced before degradation of the processing solution occurred. Degradation of the processing solution in a 5-gallon tank was first noticed at the 74th processing session when 6,965 films had been processed. Even at this point clinical radiographs processed in the solutions were acceptable. They stated that the evaluation was subjective and that no attempt was made to establish at what point radiographs became unacceptable. Even though the study showed that dental radiographic processing solutions seem to be capable of processing more radiographs of satisfactory quality than had been anticipated, this approach to quality assurance was directed toward the processing solution only.

Eastman Kodak Company, in Dental Radiography and Photography (1928), stated that new 1/2-gallon tank outfits reduce mixing operations to a minimum. It was stated that upwards of 80 dozen dental films could be put through the 1/2-gallon tanks of solutions.

Additionally, Eastman Kodak Company, in Dental Radiography and Photography (1930), stated that approximately 125 14-film full-mouth x-ray examinations could be processed in 1-gallon processing solutions. However, the solutions must be discarded at least once a month no matter how little they were used because the solutions naturally deteriorate when exposed to the atmosphere, whether or not the number of films given above were processed within that time period.

Manson-Hing (1979) presented a series of relatively simple and inexpensive quality assurance tests that check developer and fixer solution strength, darkroom integrity, safelight conditions, timer accuracy, machine output, collimation and focal spot size. An aluminum stepwedge was used to check developer strength, while the measurement of clearing time gave an indication of fixer strength. A "coin test" was used to insure proper darkroom integrity and safelight conditions, while an aluminum stepwedge was used to check x-ray machine output. A "spinning top" was used to check timer accuracy. Collimation was checked with a combination using a coin, paper clip, and thumb tack as identifying objects on periapical films. The periapical films were then traced on paper to reposition for the collimation evaluation. Focal spot condition was checked with a pinhole in a lead sheet and film supported with an empty periapical film box. Though the tests were inexpensive and simple to perform, separate tests were required for each dental radiographic problem checked.

Beeching (1980) devised a penetrometer for measuring the peak kilovoltage emitted by dental x-ray units. He modified an intraoral dental occlusal cassette (6 by 8 cm) to be used as a penetrometer to measure both peak kilovoltage between 35 and 70 kVp and the total filtration of the x-ray unit. Portions of the front of the cassette were cut away and 10 copper discs ranging in thickness from .05 to 0.5 mm in .05 mm steps were cemented inside the front portion of

the cassette. The operating kVp was determined by exposing an occlusal screen film in the modified cassette and measuring the densities underneath the copper discs. This could be done by eye, but a better result was obtained by using a densitometer. A graph of copper thickness against density resulted in a "copper number" related to peak kilovoltage. Total filtration was found by reference to the results obtained from an x-ray unit of calibrated operating kVp using a series of known filters. The occlusal cassette penetrometer proved reliable, accurate, and reproducible in use for kilovoltage testing but gave rather variable results when used for measurement of total filtration.

Gould and Gratt (1982) devised 2 quality assurance tests to detect both x-ray machine output problems and film processing changes prior to patient exposure. They designed a sensitometer specifically to use with dental x-ray film. It exposed periapical films to light emitted from an electroluminescent panel. The films were then processed and compared with a reference film to detect changes in the developer solution. X-ray machine changes were tested by exposing a periapical film to x-rays with a phantom placed over the film, then processing the film and comparing it with a reference radiograph. The phantom consisted of a plastic box containing an aluminum stepwedge, a human third molar, and wire meshes. The total system cost was \$230.00. They stated that user motivation was a necessary part of this test.

Gratt and Gould (1983) stated that criticism of their system from several dental test facilities indicated that the daily monitoring procedure required too much time. They stated (1983) that the dental auxiliaries did not like using the system as it interfered with other dental tasks. Dentists were mildly indifferent and too busy to be involved with the system. A possible solution was to shorten the procedure by using only the x-ray phantom portion of the procedure and eliminate the use of the sensitometer.

Crabtree (1983) devised a monitoring device for dental radiographic systems. Dental films were exposed to x-rays under a sheet of copper, processed, and compared with a strip of numbered density steps. A record was made of the density number that matched the test radiograph. After a set number of days the procedure was repeated and any density differences were recorded. If the match was off by 2 or more steps, exposure and/or processing procedures were checked. The procedure was then repeated to confirm the correction.

Manson-Hing (1982) devised a single quality assurance test that detects changes in both the developer solution and x-ray machine output. The test object is an 8-step aluminum stepwedge. A standard reference radiograph is prepared at the time the machine is installed or whenever the machine has been inspected, calibrated, and determined to be functioning properly, and when the processing solutions are fresh and the processor is functioning properly. The standard

reference radiograph and all subsequent test radiographs are made with the same exposure factors used for maxillary anterior radiographs using the aluminum stepwedge as the object at a constant tube film distance.

Whenever processing solutions are changed, a series of "test films" are exposed. The number of films must be greater than the average number of days of processing solutions working life. The exposed test films are stored in a lead container in a cool, dry place away from x-rays. One test film is processed in the fresh solutions and compared with the standard radiograph. If the step densities are 2 or more steps different than the standard radiograph, the x-ray machine needs to be checked. When the processed test radiograph closely matches the standard radiograph it becomes the reference radiograph for the series of test films. At the start of each day 1 test film is processed and compared with the series reference radiograph. If the stepwedge image is 2 or more steps different than the reference radiograph, the processing solutions are changed. When the solutions are changed, a new series of test films are exposed. The first processed test radiograph is compared with the original standard radiograph to check x-ray machine performance and to establish a new reference radiograph for the next series.

In the unified test, the auxiliary visually measures radiographic quality changes in the stepwedge image prior to exposing a patient to x-rays. The use of the test is based

upon the concept that when the test indicates that both x-ray machine and processing is in a "go status," loss of diagnostic information will not occur from these potential sources of error. Radiographic changes can be detected much easier from a stepwedge image than from images of teeth and bone. Cost, time and effort in preparation and use of test material is minimal, and the processing of 1 film daily does not interfere with normal auxiliary performance. This test is currently being used in a quality assurance program at the University of Alabama School of Dentistry in Birmingham. Though this test appears to be useful, it is based upon data concerning the stepwedge use in a series of individual tests. It thus lacks adequate research data to substantiate its accuracy when used as a single test for the detection of both machine and processor changes.

MATERIALS AND METHODS

A series of measurements of film, film processing, and x-ray machine variables determined the accuracy of an aluminum stepwedge for its use in quality assurance. The entire project consisted of a series of 21 individual studies. Materials and methods will be presented in 6 groups. Some of the equipment was used repeatedly throughout the entire project, and will be presented first. Materials and methods for the study of latent image fading will be presented next, followed by those items for the studies into visual performance, manual processing variables, and automatic processing variables. Finally, materials and methods for the studies into the accuracy of an aluminum stepwedge to reflect changes in x-ray machine output will be presented.

Standard Equipment

A stepwedge capable of being placed on an intraoral film and made of commercially pure aluminum was used throughout this study. Its base was 10 mm by 30 mm. There were 8 steps of 2 mm thickness each, with the surface of each step measuring approximately 4 by 10 mm. Throughout this study

the aluminum stepwedge will be referred to as the test object.

Radiography of the test object was completed with the film placed on a sheet of lead (Figure 1). The test object was placed on the film. Tube film distance was standardized at approximately 17 inches using the width of a standard intraoral film to establish end of cone to film distance. All exposures with the test object were made with beam perpendicular to the film. The long axis of the test object was positioned 90° to the long axis of the x-ray tube to minimize the "heel effect" of the x-ray beam.

X-ray films used throughout this study were Eastman Kodak X-Omat S panoramic dental film and Eastman Kodak Ultra-speed DF-58 intraoral film. All similar films in each study had the same emulsion number.

A Dupont Cronex[™] sensitometer (Figure 2) with an optical stepwedge was used to produce constant latent images in the X-Omat S film. The sensitometer was designed to consistently expose films to the same amount of light through an optical stepwedge. A pre-test confirmed the reproducibility of the sensitometer. Radiographic density measurements were made on a 2 mm diameter circular area of a radiograph with a Macbeth model TD502 densitometer (Figure 3). Each density measurement was determined by averaging the density measurements of 3 areas. Three steps of each stepwedge image were used and these steps were the highest, middle, and lowest

Figure 1

Relationship of test object, film, and
x-ray tube for film exposure

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REPRODUCED AT GOVERNMENT EXPENSE

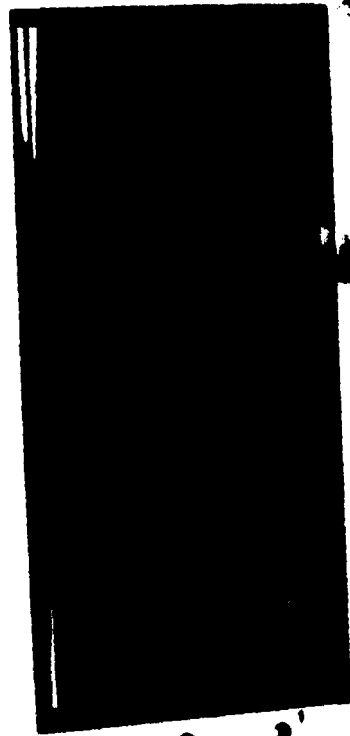


Figure 2
Dupont Cronex™ Sensitometer with (A) optical stepwedge and
(B) screen film to be exposed

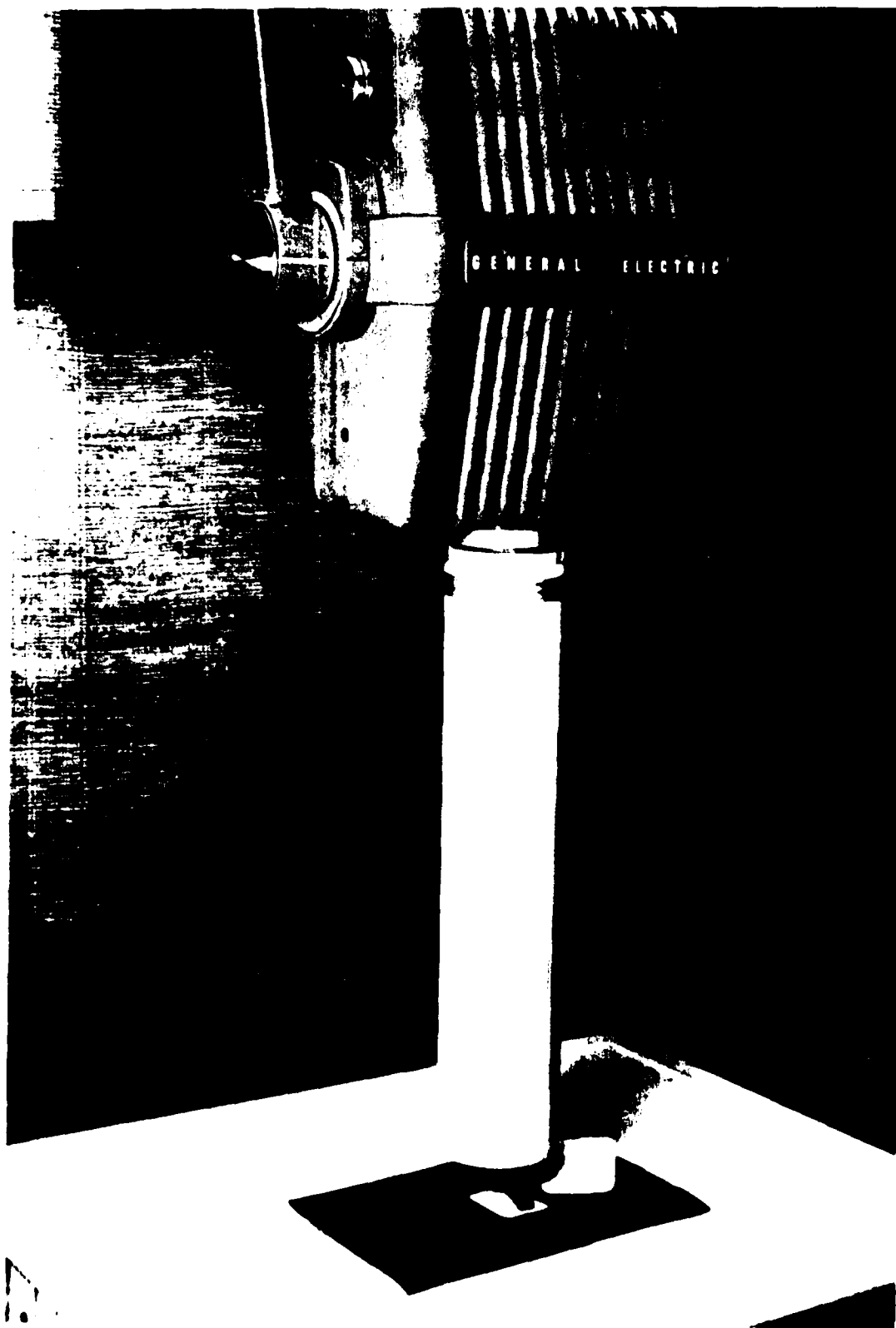
REPRODUCED AT GOVERNMENT EXPENSE



Figure 3

Macbeth model TD502 densitometer and a periplal
radiograph of the test object

REPRODUCED AT GOVERNMENT EXPENSE



density steps. Base plus fog measurements were made from unexposed films after processing.

A Phillips 410 non-replenishing automatic processor was used for all automatic processing procedures. A non-replenishing automatic processor was used because it has a greater processing variability than does a replenishing automatic processor. Eastman Kodak RP X-Omat processing solutions, which were used for all automatic processing, were mixed according to the manufacturer's directions 24 hours prior to the first processing session to allow solutions to stabilize.

A standard processing tank with solution insert tanks and temperature controls were used for all manual processing except for chemical depletion studies, in which a 1/10-gallon capacity was used. The tanks were thoroughly cleaned prior to solution mixing. Eastman Kodak GBX processing solutions were used for all manual processing, and were mixed according to the manufacturer's directions 24 hours prior to the first processing session to allow solutions to stabilize before use.

Processing temperatures were measured with the same thermometer. During tank processing, the processing rack was agitated up and down twice at the time of initial immersion and at the middle of the developing processing period. A stopwatch was used to measure all processing times. Radiographs were washed for 20 minutes in running water and dried in a hot air dryer in a dust-free room.

The darkroom was checked for light safety with a coin test, and the results were measured with the densitometer. An ML-2 and a Wratten 6B safelight were used, and the safelights were checked with a coin test. The results were measured densitometrically.

A General Electric 1000 x-ray machine with a 16 inch cylinder was used. Beam diameter was 2 3/4 inches at the cylinder end. The x-ray machine timer accuracy and reproducibility were measured with an impulse timer. X-ray output reproducibility was measured with a Victoreen 5R ion-collection chamber at 70 kVp and 10 mA. Filtration was 2.5 mm aluminum equivalent. Half-value layer of the beam was 2.15 mm aluminum equivalent at 10 mA, and 2.05 mm aluminum equivalent at 15 mA with the kVp indicator in the same position on the kVp meter.

All exposures with the test object were made with the same exposure factors used for maxillary anterior radiographs (70 kVp, 10 mA, 1 second) unless otherwise specified. This is because the test object was designed to produce a visible range of densities from light to dark, using exposure factors for maxillary anterior radiographs.

Latent Image Fading

One hundred and fifty intraoral films were individually exposed with the test object. All films were exposed with

the same exposure factors and were stored in a lead container away from x-rays.

One screen film was exposed to light in the sensitometer, developed at 70°F for 6 1/2 minutes as is required by the film, completely processed, and the step densities measured. Five of the exposed intraoral films plus 1 unexposed film were developed at the same temperature for 4 1/2 minutes as is required by the film. The step densities were measured. At subsequent three day intervals, at approximately the same time of day, another screen film was exposed to the same amount of light in the sensitometer, processed, and the step densities measured. When the step densities varied more than 5% from the first radiograph, adjustments were made in the development time to bring the step densities within 5% of the original. This procedure established the processing conditions where the developer solution functioned with the same amount of activity as for the previous radiographs. Five more exposed intraoral films plus 1 unexposed film were then simultaneously processed and the step densities measured. This procedure was repeated every 3 days for 90 days. Data were transposed to a graph of density (less base plus fog) versus time for both sensitometer and test object radiographic step densities.

Visual Performance Factors

Clinically Acceptable Density Range

A phantom was constructed using a human mandible and a wax/paraffin mixture on the dry mandible to simulate soft tissue density. A bicuspid area was used as representative of the varying thicknesses of the teeth bearing areas of the skull. Radiographs of the phantom were indistinguishable from clinical radiographs. A repositioning device to maintain consistent film placement was made. The phantom and x-ray tubehead were in a fixed position with the tube-film distance and angulation of the beam constant.

A series of 20 intraoral films were exposed using the phantom. Exposure times were adjusted to produce radiographs ranging in overall densities from obviously too light to obviously too dark. A record of exposure factors was maintained for each radiograph.

All 20 radiographs were shown independently to 20 dentists. Thirteen different dental viewboxes with normal room illumination were used to represent the various viewing conditions commonly used by dentists. The 20 viewers were asked to evaluate the overall film density on a subjective basis as being either excellent, good, fair, marginal, or not acceptable. Figure 4 shows the instructions and recording form given to each viewer.

Data were transposed to a scattergram to show the number of responses in agreement in each category, and the

Figure 4
Instructions and recording form given to each of 20
dentists for evaluating overall film density

INSTRUCTIONS

1. You will view 20 mandibular left bicuspid periapical radiographs. Each radiograph will be viewed by itself on the viewbox.
2. Consider each radiograph to be a general purpose radiograph. In other words, consider its purpose not to be limited to only caries detection or to periodontal evaluation for example.
3. Evaluate only the overall film density for each radiograph. Make the evaluation as you would in your practice.
4. Evaluate each film's density on its own merits--not relative to a previously viewed radiograph.
5. Indicate your evaluation of the overall film density as being in one of the following categories:
 - E - "Excellent"--Density needs no improvement--considered an ideal density.
 - G - "Good"--Only a small density change would make the density ideal.
 - F - "Fair"--Density is clinically acceptable but could be improved with a great amount of density change.
 - M - "Marginal"--Density is far from ideal but the film is still of useful density. Density is at the limit of what you would accept without ordering a retake.
 - N - "Not Acceptable"--Density too far from ideal to be clinically useful for general diagnostic purposes. You would order a retake of this film.

Please Circle One Category for Each Film Below:

- | | | | |
|--------------|---------------|---------------|---------------|
| 1. E G F M N | 6. E G F M N | 11. E G F M N | 16. E G F M N |
| 2. E G F M N | 7. E G F M N | 12. E G F M N | 17. E G F M N |
| 3. E G F M N | 8. E G F M N | 13. E G F M N | 18. E G F M N |
| 4. E G F M N | 9. E G F M N | 14. E G F M N | 19. E G F M N |
| 5. E G F M N | 10. E G F M N | 15. E G F M N | 20. E G F M N |

clinically acceptable density range was determined. Data from the 2 clinically determined density extremes were transposed into stepwedge density ranges using the same exposure times with the test object in place of the phantom. The clinically acceptable density range was expressed in terms of its range, in step densities, as reflected by the test object.

Visual Matching

A series of 10 intraoral films were exposed with the test object. One film was exposed with exposure factors normally used for maxillary anterior periapical radiographs. This radiograph was the reference radiograph. A second radiograph was exposed with the same exposure factors and was used as a duplicate. A third radiograph was made by varying the exposure time to provide a range of step densities 1/2 step darker than the reference radiograph. The 1/2-step density change was identified densitometrically. The fourth film was exposed to produce a range of step densities 1/2 step lighter. The fifth and sixth films were exposed to produce a 1-step change lighter and darker. The seventh and eighth films were exposed to produce a 1 1/2-step change lighter and darker than the reference radiograph. The ninth and tenth films were exposed to produce a 2-step change lighter and darker than the reference radiograph.

To simulate viewing conditions commonly used by dental auxiliaries, 4 different viewboxes were used with ordinary overhead illumination in 4 different rooms. Thirty dental

auxiliaries were the readers. Eighteen were dental assistant students, and each had approximately 8 months of dental assisting education. Five readers were senior dental hygiene students with approximately 1 1/2 years dental hygiene education. Four of the readers were dental secretaries with no experience with radiographic interpretation. Three of the readers were dental assistants with an average experience of 12 years.

The radiographs were shown individually to each of the 30 dental auxiliaries. The reference radiograph was individually matched with each of the other 9 radiographs which were randomized. The readers were asked to position the reference radiograph and each radiograph where similar steps have the same density. The readers were instructed to position the test film halfway between 2 steps if whole steps could not be matched. Once a match was made, the readers were instructed to double check their decision by moving the test radiograph up and down to check for the possibility of a better match. The number of steps and the direction (lighter or darker) of the positioning of the test film, relative to the reference film, was recorded.

Data in the form of positioning errors, in terms of the number of steps missed, were determined. A histogram was made to show the percentage of correct responses. The accuracy of the visual matching of similar density steps was thus determined.

Manual Processing Variables

Developer Dilution

Fifty intraoral films were individually exposed to x-rays with the test object. Fresh processing solutions were used, and constant processing times and temperatures were maintained.

A screen film was exposed in the sensitometer, processed, and the step densities measured. Five of the exposed intraoral films plus 1 unexposed film were simultaneously processed and the step densities measured.

A fresh developer solution was diluted with water to 90% of the original concentration, and the same procedures were repeated. Similar measurements were made at 10% intervals for 80% through 10% concentrations. The relationship between density (less base plus fog) and developer concentration of sensitometer and test object radiographic step densities was determined.

Development Time Variations

Forty intraoral films were individually exposed to x-rays with the test object. All processing temperatures were kept constant.

A film was exposed in the sensitometer and developed for 1 minute and 26 seconds (22% of optimum development time). The step densities were then measured. Five of the exposed

intraoral films plus 1 unexposed film were simultaneously developed for 1 minute (also 22% of optimum development), and the step densities were measured.

The same procedures were repeated in 1 minute increments for the test object films and proportionally for the sensitometer films. Data showed the relationship between density (less base plus fog) and development time changes for sensitometer and test object radiographic step densities.

Developer Aging

One hundred and fifty intraoral films were individually exposed to x-rays with the test object. The films were stored in a lead container away from x-rays. Fresh 5-gallon processing solutions were used.

One screen film was exposed in the sensitometer, processed, and the step densities measured. Five of the exposed intraoral films plus one unexposed film were processed, and the step densities measured. The sensitometer film was developed for 6 1/2 minutes as is required by the film, and all periapical films were developed for 4 1/2 minutes. All processing was at 70°F.

Three days later, at approximately the same time of day, the same procedures were repeated. Processing solutions were kept covered during the 3-day interval between processing sessions. The amount of time that the processing solutions were uncovered was recorded so that at the end of

the 90-day period the total amount of uncovered air exposure was known.

The same procedures were repeated every 3 days for 90 days. Data were transposed to a graph of density (less base plus fog) versus time for sensitometer and test object radiographic step densities.

Developer Chemical Depletion

Intraoral films were exposed with the phantom using the optimum exposure factors for the radiographs determined to be of excellent overall density in the experiment previously conducted to determine the clinically acceptable density range.

Fifty intraoral films were individually exposed to x-rays with the test object. Fresh 1/10-gallon developer solution and a 5-gallon fixer solution were used.

Fifty of the exposed films made with the phantom were developed at 70°F for 4 1/2 minutes. These films were not rinsed or fixed since they were used to degrade the developer solution only.

A film was exposed in the sensitometer, processed, and the step densities measured. Five of the exposed intraoral films plus 1 unexposed film were simultaneously processed and the step densities measured. The sensitometer film was developed for 6 1/2 minutes, as is required by the film, and the intraoral films were processed for 4 1/2 minutes. All processing was at 70°F.

The same procedures were repeated in increments of 50 films exposed to x-rays with the phantom until the developer solution was obviously depleted. Data were transferred to a graph of density (less base plus fog) versus number of films processed through the developer solution for both sensitometer and test object radiographic step densities.

Fixing Time Variations

Thirty-five intraoral films were individually exposed to x-rays with the test object. Fresh 5-gallon processing solutions were used. All processing was at 70°F.

One film was exposed in the sensitometer, developed, and fixed for 5 minutes, as is required by the film. The step densities were then measured. Five of the exposed intraoral films plus 1 unexposed film were simultaneously developed and fixed for twice the time for sensitometer film, or 10 minutes. The step densities were then measured.

The same procedures were repeated using fixing times of 4, 3, 2, 1, 1/2, and 1/4 minutes for the sensitometer film and 8, 6, 4, 2, 1, and 1/2 minutes for the periapical films. Data were transposed to a graph of density (less base plus fog) versus fixing time for both sensitometer and test object radiographic step densities.

Fixer Temperature Variations

Thirty intraoral films were individually exposed to x-rays with the test object. Fresh 5-gallon processing solutions were used. Developer and rinse temperatures were 70°F for all processing, and all processing times were kept constant for the sensitometer films as well as for the intraoral films.

One film was exposed in the sensitometer, developed, and rinsed. This film was then fixed for 5 minutes at 60°F and the step densities measured. Five of the exposed intraoral films plus 1 unexposed film were simultaneously developed and fixed for 10 minutes at 60°F and the step densities measured.

The fixer temperature was increased to 65°F and the same procedures were repeated. Similar measurements were made at 5° intervals from 60°F to 80°F. One measurement was also made at 83°F. Data were transposed to a graph of density (less base plus fog) versus fixer temperature for both sensitometer and test object radiographic step densities.

Fixer Aging

One hundred and fifty intraoral films were individually exposed to x-rays with the test object. All films were stored in a lead container away from x-rays. Fresh 5-gallon processing solutions were used at 70°F.

One film was exposed in the sensitometer, processed, and the step densities measured. Five of the exposed intraoral films plus 1 unexposed film were then simultaneously processed and the step densities measured. Developing and fixing times were kept constant at optimum for both sensitometer and intraoral films.

Three days later, at approximately the same time of day, the same procedures were repeated. Processing solutions were kept covered during the 3-day interval between processing sessions. The same procedure was repeated every 3 days for 90 days. The amount of time that the processing solutions were uncovered was recorded so that at the end of the 90-day period the total amount of uncovered air exposure was known. Data were transposed to a graph of density (less base plus fog) versus time for both sensitometer and test object radiographic step densities.

Automatic Processing Variables

Developer Dilution

Fifty intraoral films were exposed to x-rays with the test object. Fresh 2-quart rapid processing solutions were used. All processing was at 86°F as set by the automatic processor.

A section of screen film was cut to the size of intraoral film to allow it to fit into the processing rack of the automatic processor. The screen film was processed and the

(step densities were measured. Five of the intraoral films plus 1 unexposed film were simultaneously processed and the step densities measured. The same procedures were repeated after diluting a fresh developer solution with water to 90% of the original concentration. Similar measurements were made using 80% through 10% concentrations at 10% intervals. Data were transposed to a graph of density (less base plus fog) versus developer concentration for both sensitometer and test object radiographic step densities.

Developer Temperature Variations

Seventy intraoral films were individually exposed to x-rays with the test object. Fresh 2-quart processing solutions were used. Fixer solution and wash temperatures were maintained at 86°F for all processing.

One film was exposed in the sensitometer. The developer solution was cooled to 60°F, and the sensitometer film was processed along with 5 exposed test object films plus 1 unexposed film. The step densities were then measured.

The same procedures were repeated at 2° intervals from 60°F to 86°F. Data were transposed to a graph of density (less base plus fog) versus developer solution temperature for both sensitometer and test object radiographic step densities.

Developer Aging

Eighty intraoral films were individually exposed to x-rays with the test object. All films were exposed with the same exposure factors and were stored in a lead container away from x-rays. Fresh 2-quart processing solutions were used. All processing was at 86°F.

One film was exposed in the sensitometer and simultaneously processed with 5 of the exposed intraoral films plus 1 unexposed film. The same procedures were repeated every other day, at approximately the same time of day, for 30 days. Data were transposed to a graph of density (less base plus fog) for both sensitometer and test object radiographic step densities.

Developer Chemical Depletion

Intraoral films were exposed with the phantom using the exposure factors for the radiographs determined to be of excellent overall density in the experiment previously conducted in determining the clinically acceptable density range. Sixty-five intraoral films were individually exposed to x-rays with the test object. Fresh 1/10-gallon developer and fixer solution were used. Automatic processing was simulated by manually using the same processing times and temperatures as in the automatic processor.

Forty of the previously exposed intraoral radiographs with the phantom were developed at 86°F for 1 minute. These

(radiographs were not fixed or washed since they were used only to degrade the developer solution.

A film was exposed in the sensitometer and simultaneously processed with 5 intraoral films exposed to x-rays with the test object plus 1 unexposed film. The step densities were then measured. All processing was with the same temperature and with the same processing times.

The same procedures were repeated in increments of 40 films exposed to x-rays with the phantom until the developer solution was obviously depleted. Data were transposed to a graph of density (less base plus fog) versus number of films processed through the developer for both sensitometer and test object radiographic step densities.

Fixer Dilution

Fifty intraoral films were exposed to x-rays with the test object. Each film was exposed with the same exposure factors to produce similar latent images. Fresh 2-quart processing solutions were used. All processing was at 86°F.

A film was exposed in the sensitometer and simultaneously processed with 5 of the exposed intraoral films plus 1 unexposed film. The step densities were then measured.

A fresh fixer solution was diluted with water to 90% of the original concentration and the same procedures were repeated. Similar measurements were made for 80% through 10% concentration at 10% intervals. Data were transposed

to a graph of density (less base plus fog) versus fixer solution concentration for both sensitometer and test object radiographic step densities.

Fixer Temperature Variations

Thirty-five intraoral films were individually exposed to x-rays with the test object. Fresh 2-quart processing solutions were used. Developer and wash temperatures were maintained at 86°F for all processing.

One film was exposed in the sensitometer. The fixer temperature was cooled to 60°F and this film was simultaneously processed with 5 of the exposed intraoral films plus 1 unexposed film. The step densities were then measured. The same procedures were repeated at 5° intervals from 60°F to 85°F and at 86°F. Data were transposed to a graph of density (less base plus fog) versus fixer temperatures for both sensitometer and test object radiographic step densities.

Fixer Aging

Eighty intraoral films were individually exposed to x-rays with the test object. All films were exposed with the same exposure factors and were stored in a lead container away from x-rays. Fresh 2-quart processing solutions were used. All processing was at 86°F.

One film was exposed in the sensitometer and simultaneously processed with 5 of the exposed intraoral films plus

1 unexposed film. The same procedures were repeated every other day, at approximately the same time of day, for 30 days. Data were transposed to a graph of density (less base plus fog) versus time for both sensitometer and test object radiographic step densities.

Machine Output Changes

kVp Variations

Five intraoral films were individually exposed to x-rays with the test object at 10 mA for 1 second at every 5-kVp interval from 50 to 90 kVp. Fresh 5-gallon solutions were used, and all processing was at 70°F. Half value layer for each kVp was measured.

One film was exposed in the sensitometer, processed, and the step densities measured. The 5 intraoral films exposed at 50 kVp plus 1 unexposed film were simultaneously processed and the step densities measured.

The same procedures were repeated for each kVp. Data were transposed to a graph of density (less base plus fog) versus kVp for both sensitometric and test object radiographic step densities.

mAs Variations

Five intraoral films were exposed to x-rays with the test object at 10 mA and 70 kVp for each of 18 impulse settings from 3 to 300 impulses. Five intraoral films were

also similarly exposed at 15 mA with the kVp indicator in the same position on the kVp meter, for each of 18 impulse settings from 3 to 300 impulses. A total of 180 intraoral films were exposed. Fresh 5-gallon processing solutions were used.

A film was exposed in the sensitometer, processed, and the step densities measured. The 5 intraoral films exposed at 10 mA for 3 impulses plus 1 unexposed film were simultaneously processed and the step densities measured. The same procedures were repeated for each of the other 17 combinations. The same procedures were also repeated for all mAs combinations at 15 mA. Data were transposed to graphs of density (less base plus fog) versus mAs for both sensitometer and test object radiographic step densities.

RESULTS

The effectiveness of an aluminum stepwedge to detect x-ray exposure changes and processing activity from a radiograph depends upon the stability of the latent image and the visual performance of the operator. The results of the investigation into latent image fading will be presented first. This will be followed by the results of the studies into visual performance factors. Next, the results of the accuracy of the test object to detect manual processing changes will be presented, followed by automatic processing changes. Finally, the results of the accuracy of the test object to detect x-ray machine changes will be presented.

Latent Image Fading

Latent image fading was determined by processing 5 of 150 periapical films previously exposed to x-rays with the test object every 3 days for 90 days. Developer solution activity was maintained at $100\% \pm 5\%$ by processing 1 film exposed by the sensitometer at each of 31 processing sessions. Twenty-six of the processing sessions had developer solution activity within 5% of full processing, and no

alteration in developing time was necessary to maintain optimum development activity.

Figure 5 shows the relationship between density (less base plus fog) and time of sensitometer and test object radiographs of 3 density levels. There was a gradual drop in density of both sensitometer and periapical radiographs during the first 48 days. Since all sensitometer films had identical latent images, the density drop represents a slight decrease in developer solution activity. Fresh developer solutions were mixed on the 49th and 76th days of the 90-day period. Step densities of the test object radiographs closely paralleled the step densities of the sensitometer radiographs at all density levels throughout the 90-day period. No densitometrically detectable latent image fading occurred during the 90-day period.

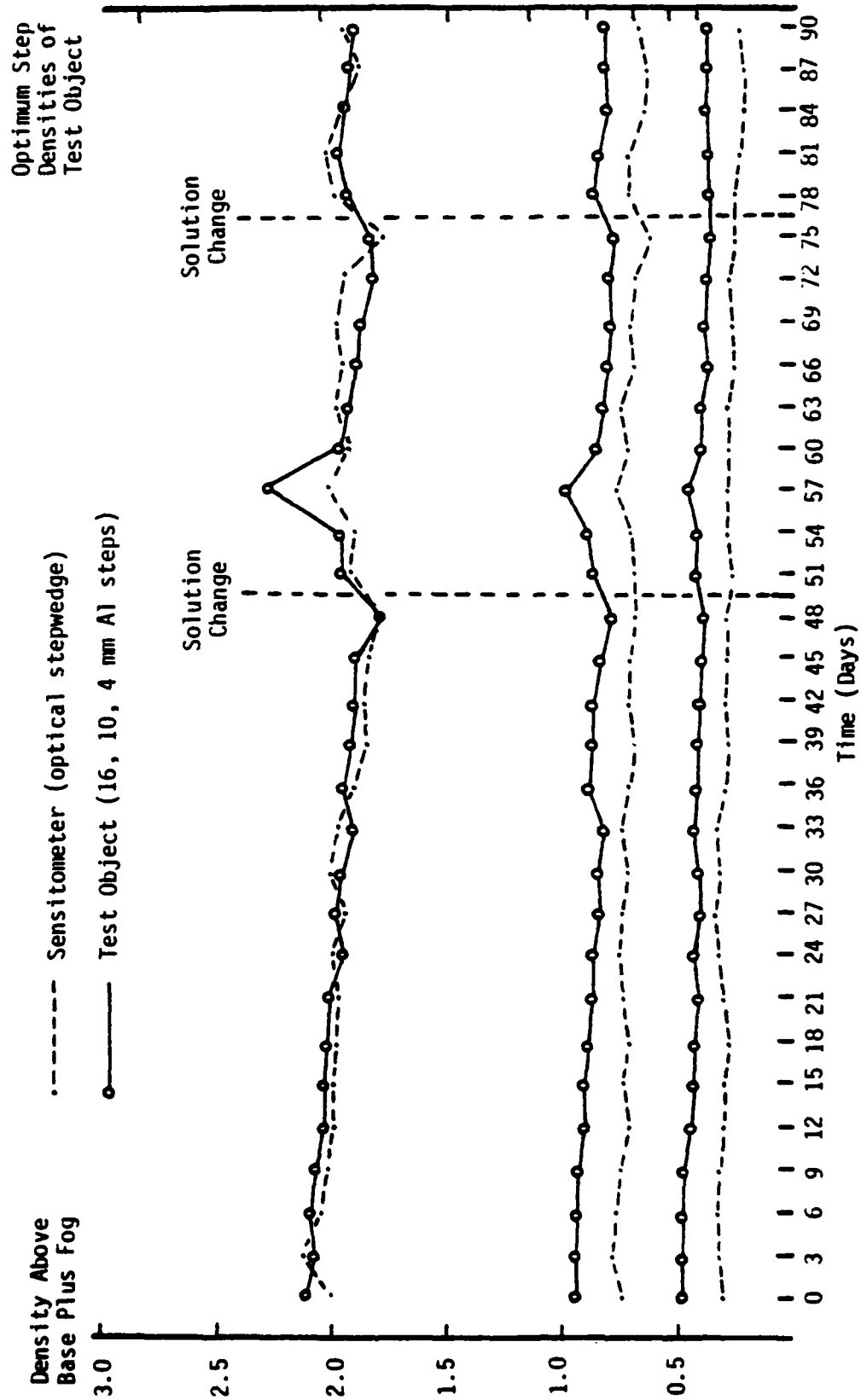
The results indicate that since the test object step densities closely paralleled the sensitometer step densities the test object functioned with the same accuracy as the sensitometer in monitoring developer solution activity under these conditions.

Visual Performance Factors

The range of overall radiographic densities clinically acceptable to dentists was ascertained and transposed to a range of step densities in periapical radiographs of the test object. The ability of dental auxiliaries to match

Figure 5

Relationship of radiographic density (less base plus fog) to time of
sensitometer and test object radiographs of 3 density levels



visually similar step densities was studied to measure the magnitude of error in this visual task.

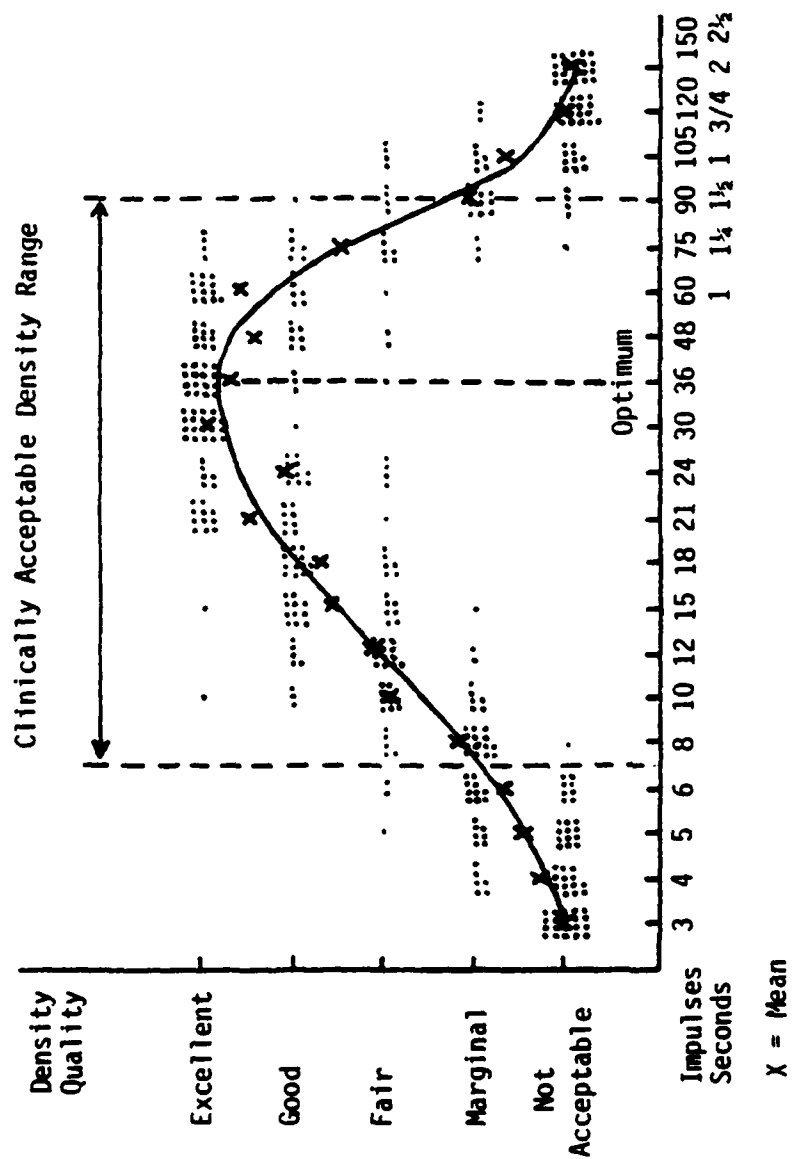
Clinically Acceptable Density Range

Twenty dentists viewed separately 20 mandibular bicuspid radiographs ranging in overall density from obviously too light to obviously too dark. Each dentist evaluated and categorized each radiograph into one of 5 categories. The 20 viewers represented 211 years total professional experience with a range of 1 to 36 years, with a mean of 10.5 years experience. Eleven were graduate dental students and 9 were dental school faculty members.

Figure 6 shows the results of the evaluation. The weighted mean for each radiograph shows that the optimum exposure was 36 impulses. Radiographs with acceptable densities were selected as being between marginal light to marginal dark densities. Of the 20 responses to the radiographs made with 6 impulses there was 60% agreement that the radiograph was marginal or fair. Density evaluations of the radiograph made with 8 impulses indicated 95% agreement that it was marginal or fair. Of the 20 responses to the radiograph made with 105 impulses there was 50% agreement that the radiographic density was marginal or fair. Density evaluations of the radiograph made with 90 impulses indicated 80% agreement that the radiograph was marginal, fair, or good. There was 95% agreement that the radiograph made with 75 impulses was marginal to excellent. Marginally light

Figure 6

The relationship between radiographic density quality evaluation by
20 dentists of radiographs made with exposures of 3-150 impulses



radiographic densities were made with 7 impulses, and marginally dark radiographs were made with 90 impulses. Thus, clinically acceptable radiographs were made with exposures ranging from 7 to 90 impulses. Of the 13 radiographs exposed within this range there was a total of 260 responses with 97.7% agreement that these radiographs had overall radiographic densities that ranged from marginal to excellent.

Visual Matching

Thirty dental auxiliaries individually matched a reference radiograph of the test object with each of 9 different test radiographs. The error involved with the visual task of matching similar density steps was determined.

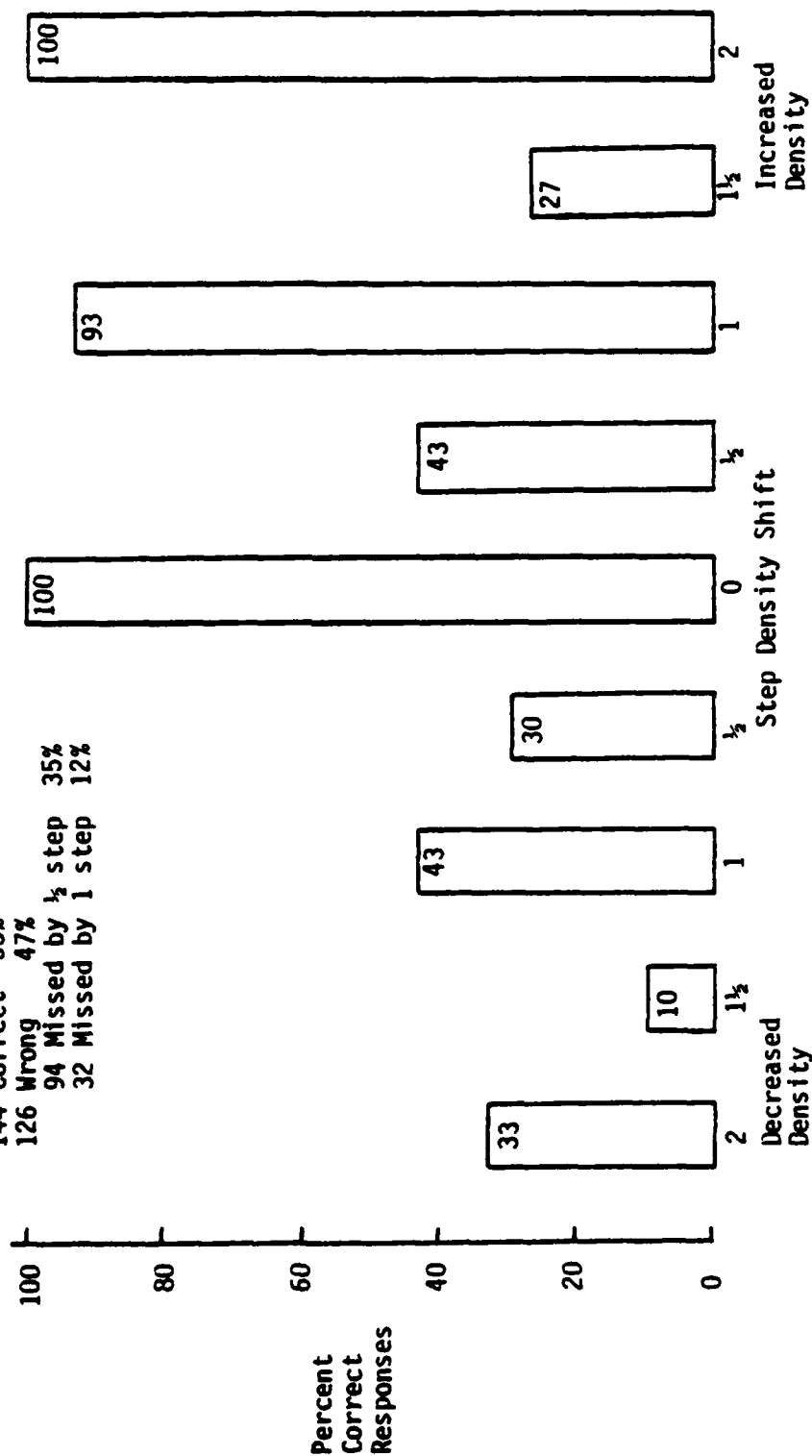
Figure 7 shows the percent correct responses of 30 readers for visual matching for the 9 different step density shifts. Of the total of 270 responses, 144 (53%) were correct and 126 (47%) were incorrect. Ninety-four (75%) of the mismatched responses resulted from an error of 1/2 step, and 32 (25%) mismatched the step densities by 1 step. None of the 30 readers mismatched similar step densities by more than 1 step.

The results indicate that an average of 73% of the responses were correct for the matching of radiographs with step densities shifts equal to or greater than the reference radiograph. An average of 29% of the responses were correct for the matching of radiographs with density shifts less than the reference radiograph.

Figure 7

The percent correct responses of 30 dental auxiliaries for visual matching of a reference radiograph with 9 radiographs having 9 different step densities of up to 2 step densities greater and lesser than the reference radiograph

30 Readers
270 Responses
144 Correct 53%
126 Wrong 47%
94 Missed by 1/2 step 35%
32 Missed by 1 step 12%



67

Manual Processing Variables

A series of independent experiments measured the accuracy of the test object to detect changes in manual processing solution concentrations, time, and temperature, as well as chemical depletion and solution aging. The results are presented for each variable separately.

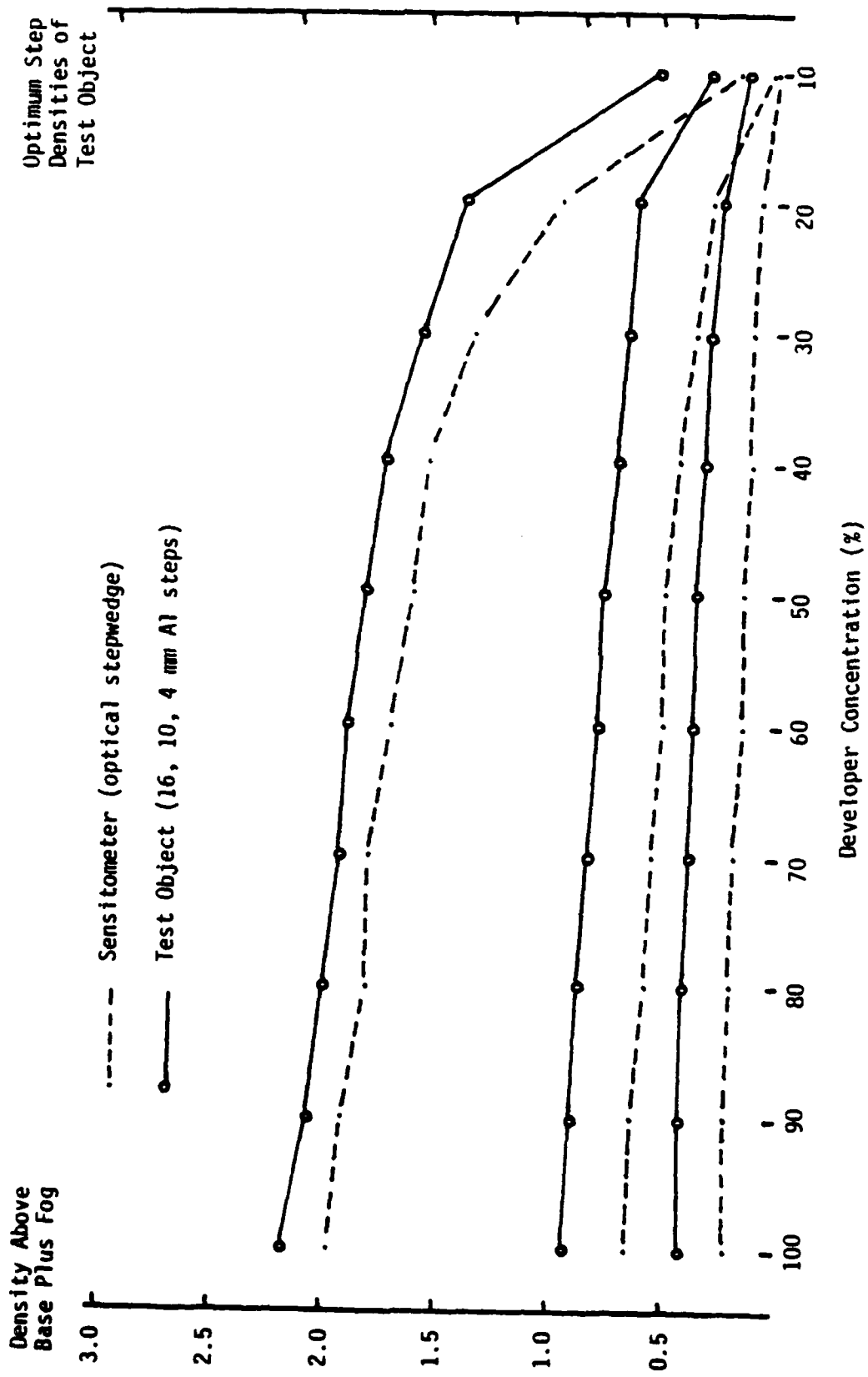
Developer Dilution

Developer solutions were diluted with water from 100% to 10% concentration at 10% increments to measure radiographic density changes of the test object with concentration. All other variables were kept constant.

Figure 8 shows the relationship between density (less base plus fog) and developer solution concentration for test object and sensitometer radiographs. A developer concentration of 60% produced a step density shift of approximately 1/2 step in the periapical radiographs. Accordingly, a 30% concentration produced approximately a 1-step density shift, while a 15% concentration produced a 2-step shift in step densities. The data show that the sensitometer and test object step densities closely paralleled each other. The periapical radiographs of the test object functioned with the same accuracy as the sensitometer in measuring or monitoring developer solution dilution.

Figure 8

The relationship between radiographic density (less base plus fog) and developer solution concentration of sensitometer and test object radiographs of 3 density levels in manual processing



Development Time Variations

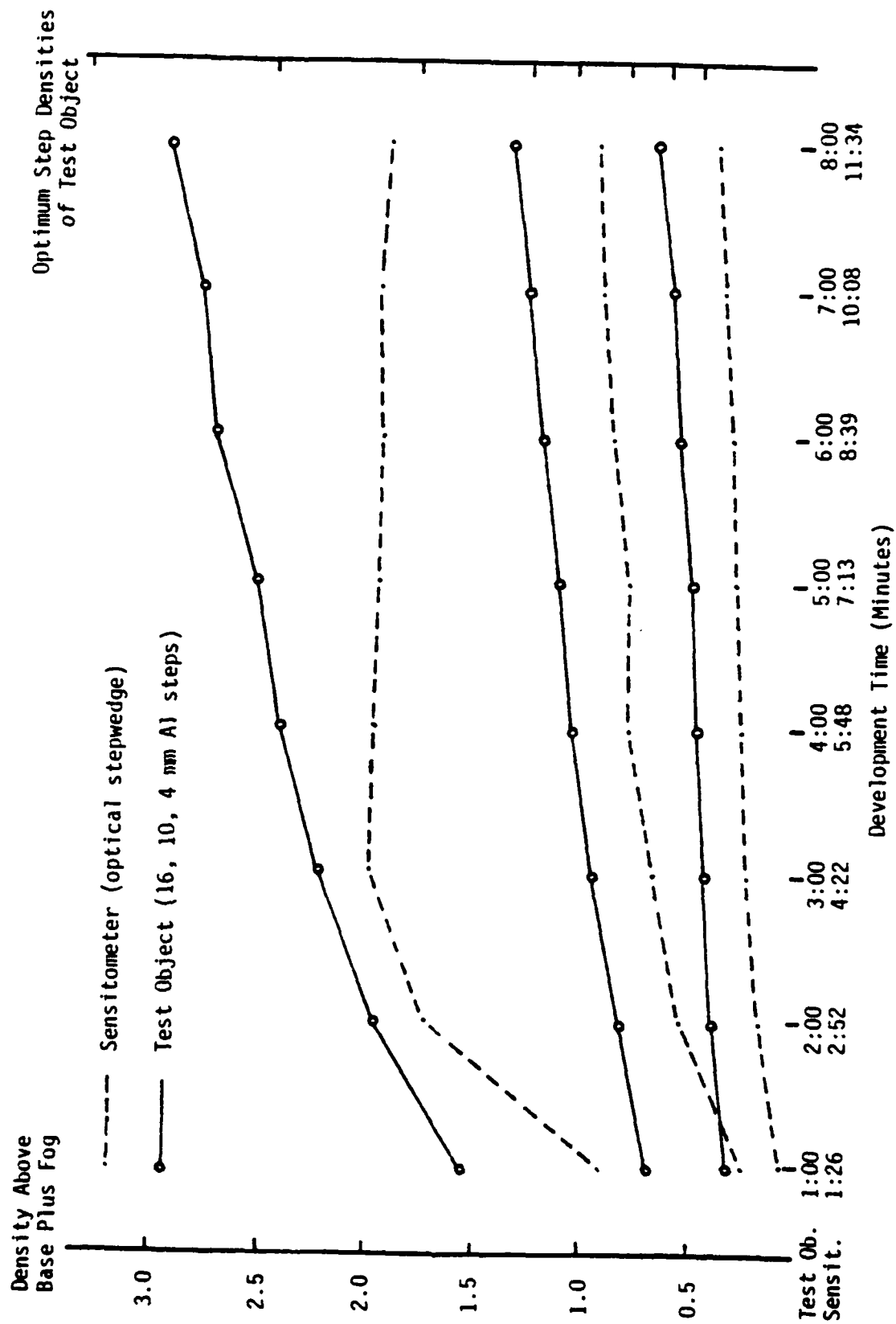
Development time was varied from 1 to 8 minutes to measure the radiographic density changes of the test object with development time. The optimum development time for periapical films was 4 1/2 minutes and 6 1/2 minutes for the sensitometer films. Variations in development time were made in 1-minute increments for the periapical films and proportionately longer for the light-exposed sensitometer films.

Figure 9 shows the relationship between density (less base plus fog) and development time of sensitometer and test object radiographs of 3 density levels. The data show that a 1/2-minute change in development time, longer or shorter than optimum, produced approximately a 1/2-step density shift in the periapical radiographs. Accordingly, a 3-minute change, longer or shorter than optimum, produced approximately a 1-step density shift.

The data show that the test object step densities closely paralleled the sensitometer step densities, with the exception of the 4 mm-step density. The sensitometer density at this exposure obtained a maximum density after 4 minutes and 22 seconds development time. The density of the 4 mm-step of the test object continued to increase with development time up through 8 minutes. The other 2 lower step densities closely paralleled the sensitometer step densities.

Figure 9

The relationship between radiographic density (less base plus fog) and development time of sensitometer and test object radiographs of 3 density levels in manual processing



Developer Temperature Variations

Developer temperature was varied from 60°F to 82°F in 2° increments and at 83°F to measure radiographic density changes of the test object with developer temperature variations. All other variables were kept constant.

Figure 10 shows the relationship between density (less base plus fog) and developer temperature, of sensitometer and test object radiographs of 3 density levels. A temperature increase or decrease of 10°F from optimum temperature produced approximately a 1/2-step density shift in the test object radiographs. The data show that the test object and sensitometer step densities closely paralleled. The radiographs of the test object functioned with the same accuracy as the sensitometer in detecting developer temperature changes.

Developer Aging

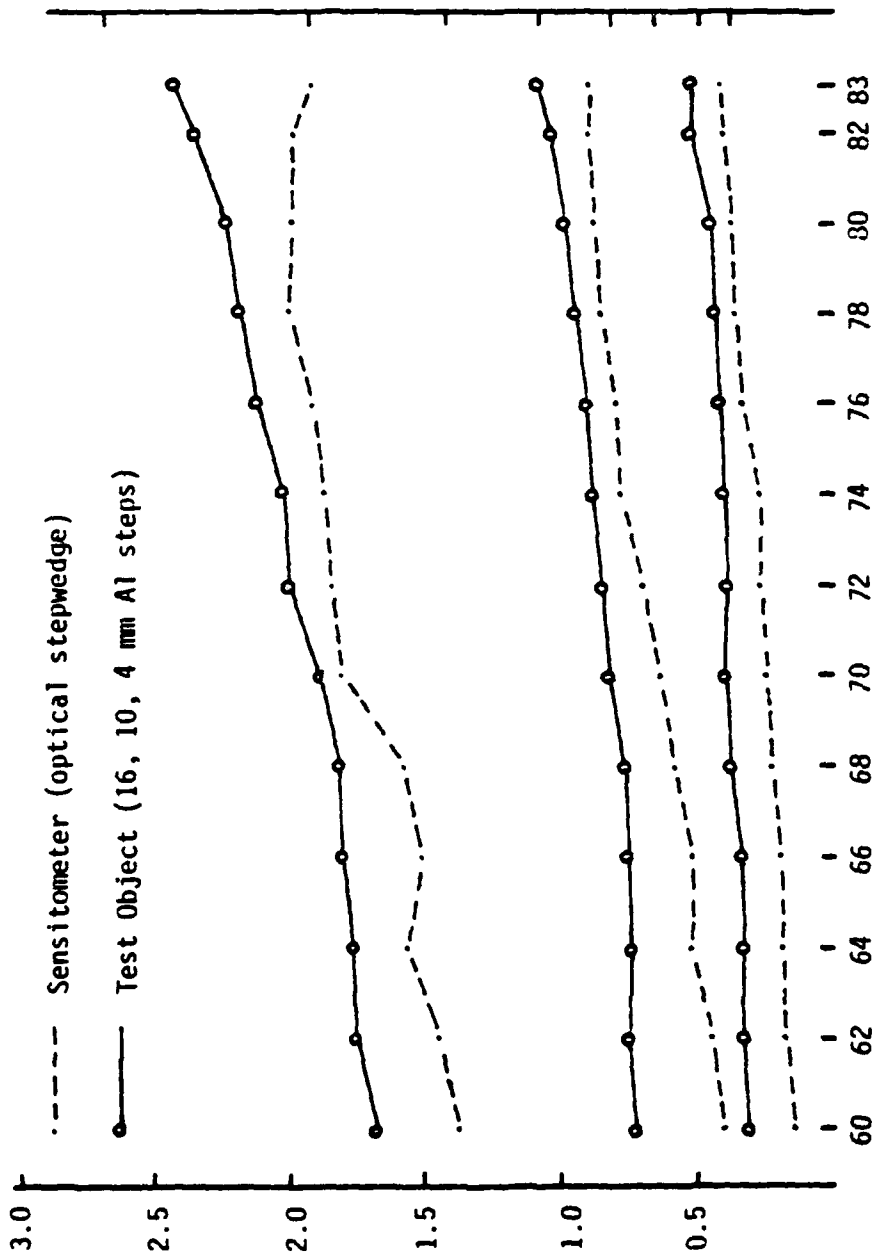
Radiographic density changes were measured with degradation of developer solution due to time and oxidation. Five of 150 periapical films exposed to x-rays with the test object were processed every 3 days for 90 days. Surface area of the 5-gallon developer solution was 59 square inches or 11.8 square inches per gallon. The developing solution was covered throughout the 90-day period with the exception of approximately 30 hours test time.

Figure 10

The relationship between radiographic density (less base plus fog) and development temperature of sensitometer and test object radiographs of 3 density levels in manual processing

Optimum Step
Densities of
Test Object

Density Above
Base Plus Fog



Development Temperature (°F)

Figure 11

The relationship between radiographic density (less base plus fog) and time of sensitometer and test object radiographs of 3 density levels in manual processing

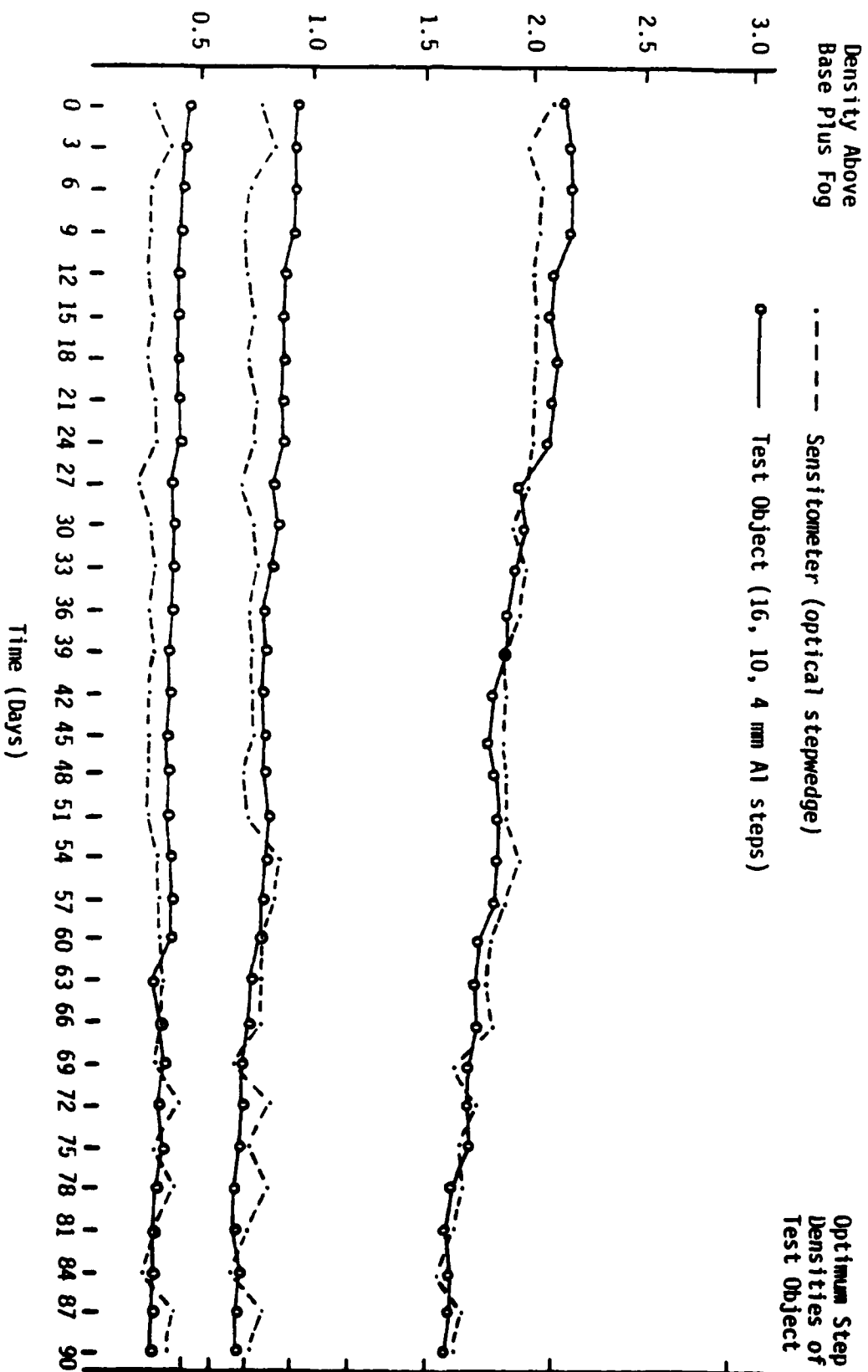


Figure 11 shows the relationship between density (less base plus fog) and time of sensitometer and test object radiographs of 3 density levels. Developer solution degradation with time and oxidation in the first 45-day period produced approximately a 1/2-step density shift in the test object radiographs, while degradation over the entire 90-day period produced approximately a 1-step density shift.

The sensitometer step densities and the test object step densities closely paralleled. The parallelism indicates that the test object functioned with the same accuracy as the sensitometer in detecting changes in developer solution age. Since the sensitometer films were freshly exposed at each 3-day period, the data show that any latent image fading of the test object radiographs made no densitometrically detectable contribution to the gradual density shift during the 90-day period.

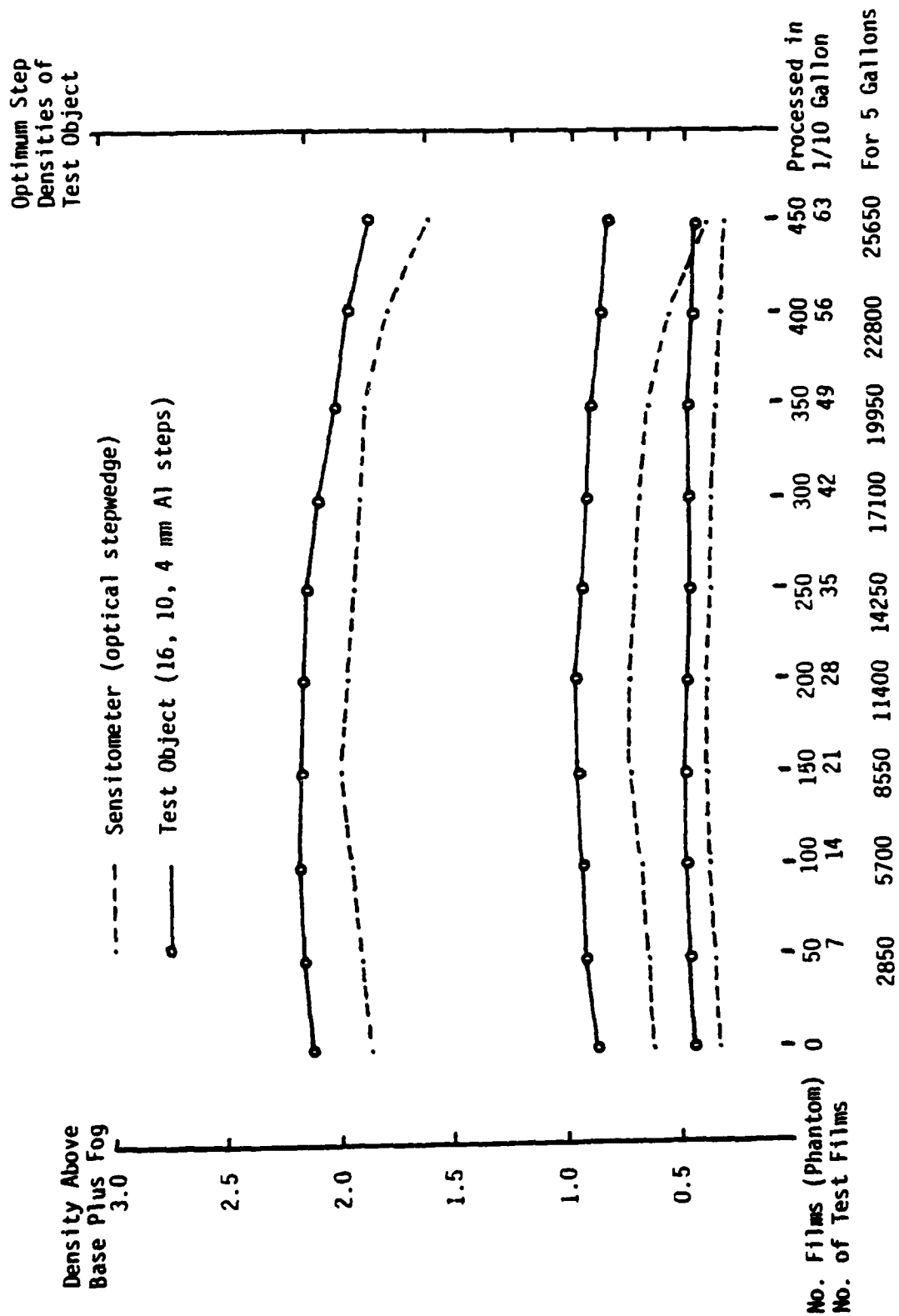
Developer Chemical Depletion

Periapical films were exposed to x-rays with the phantom and processed in 50 film increments to measure radiographic density changes due to chemical depletion of the developer solution. Each set of 50 periapical films was processed in 1/10-gallon developer.

Figure 12 shows the relationship between density (less base plus fog) and number of films processed of radiographs. This number of films processed in one-tenth sensitometer and test object radiographs of 3 density levels. Developer

Figure 12

The relationship between radiographic density (less base plus fog) and number of perispherical films processed of sensitometer and test object radiographs of 3 density levels in manual processing



solution depleted by 450 periapical films plus 63 test films produced lighter step densities that were approximately 1-step density shift from fully processed periapical radiographs. This number of films processed in 1/10-gallon of developer extrapolates linearly by volume to 22,500 periapical films plus 3,150 test films processed in 5 gallons of developer. The data show that the sensitometer and test object radiographic densities closely paralleled each other. The test object functioned with the same accuracy as the sensitometer in detecting changes in developer solution due to chemical depletion.

Fixer Dilution

Fixer solution was diluted with water from 100% to 10% concentration at 10% increments to measure radiographic density changes of the test object with fixer concentration. All other variables were kept constant.

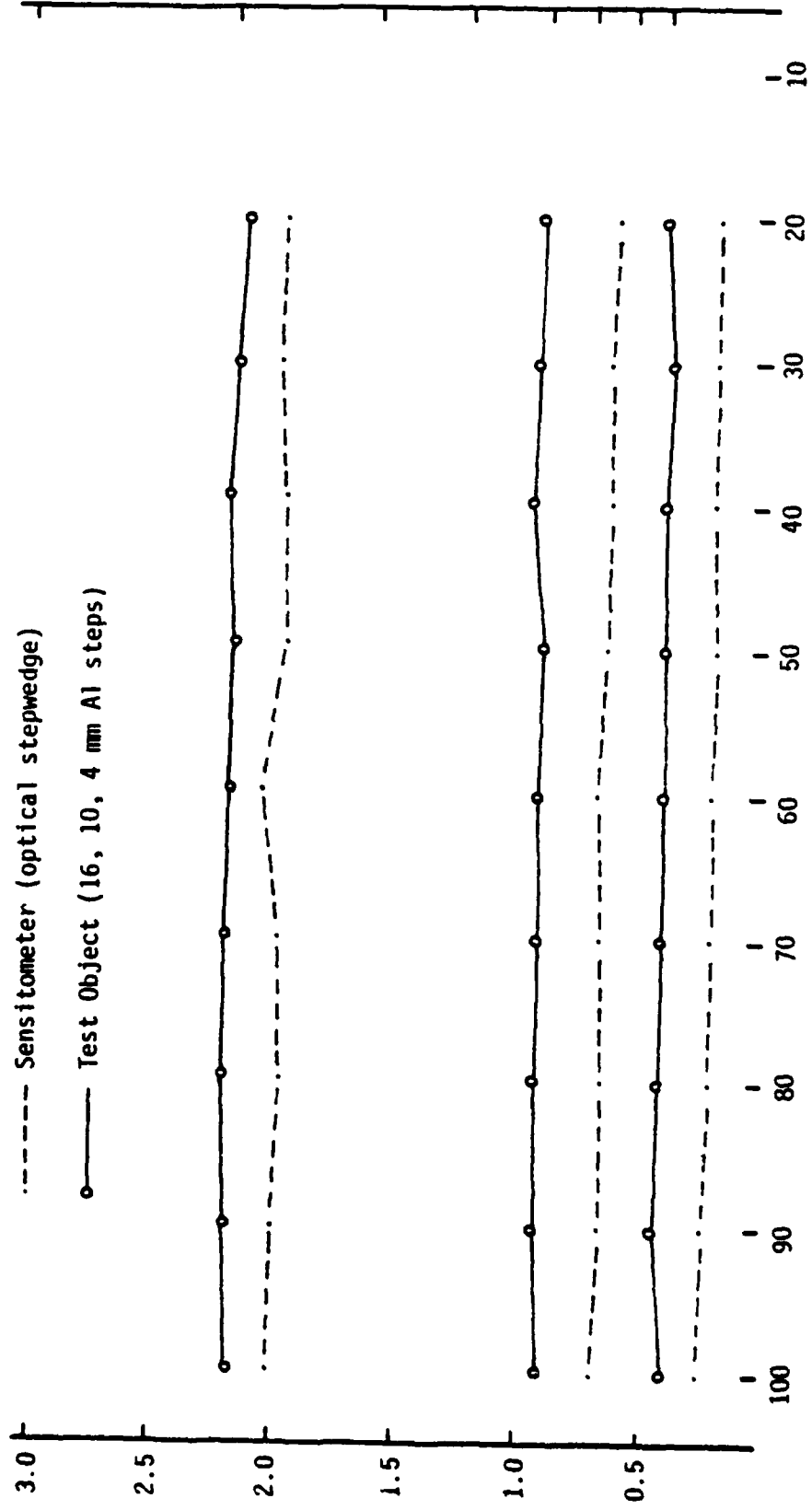
Figure 13 shows the relationship between density (less base plus fog) and fixer solution concentration for test object and sensitometer radiographs. There was no density change in sensitometer or test object radiographs with concentration changes from 100% through 20%. A 10% fixer concentration produced unfixed radiographs.

The data show that the sensitometer and test object radiographic step densities were closely parallel. The test object functioned with the same accuracy as the sensitometer in measuring or monitoring fixer solution dilution.

Figure 13

The relationship between radiographic density (less base plus fog) and
fixer solution concentration of sensitometer and test object
radiographs of 3 density levels in manual processing

Density Above
Base Plus Fog



Fixer Concentration (%)

84

Fixing Time Variations

Fixing time was varied from 10 minutes to 1/2 minute, to measure the radiographic density changes of the test object with fixing time. Fixing time reductions for light exposed sensitometer films were varied proportionately to the times used for the periapical films.

Figure 14 shows the relationship between density (less base plus fog) and fixing time of sensitometer and test object radiographs of 3 density levels. There was no density shift as the fixing time varied from 10 minutes through 1 minute for the periapical radiographs of the test object. A 1/2-minute fixing time produced unfixed radiographs.

The data show that the sensitometer and test object radiographs closely paralleled each other. The test object functioned with the same accuracy as the sensitometer in detecting fixing time reductions.

Fixer Temperature Variations

Fixer temperature was varied from 60°F to 80°F at 5°-increments and at 83°F to measure radiographic density changes with fixer temperature variations. All other variables were kept constant.

Figure 15 shows the relationship of density (less base plus fog) and fixer temperature of sensitometer and test object radiographs of 3 density levels. There was no density shift as fixer temperature was varied from 60°F to 83°F.

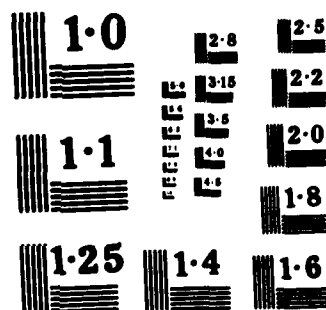


Figure 14

The relationship between radiographic density (less base plus fog) and
fixing time of sensitometer and test object radiographs of
3 density levels in manual processing

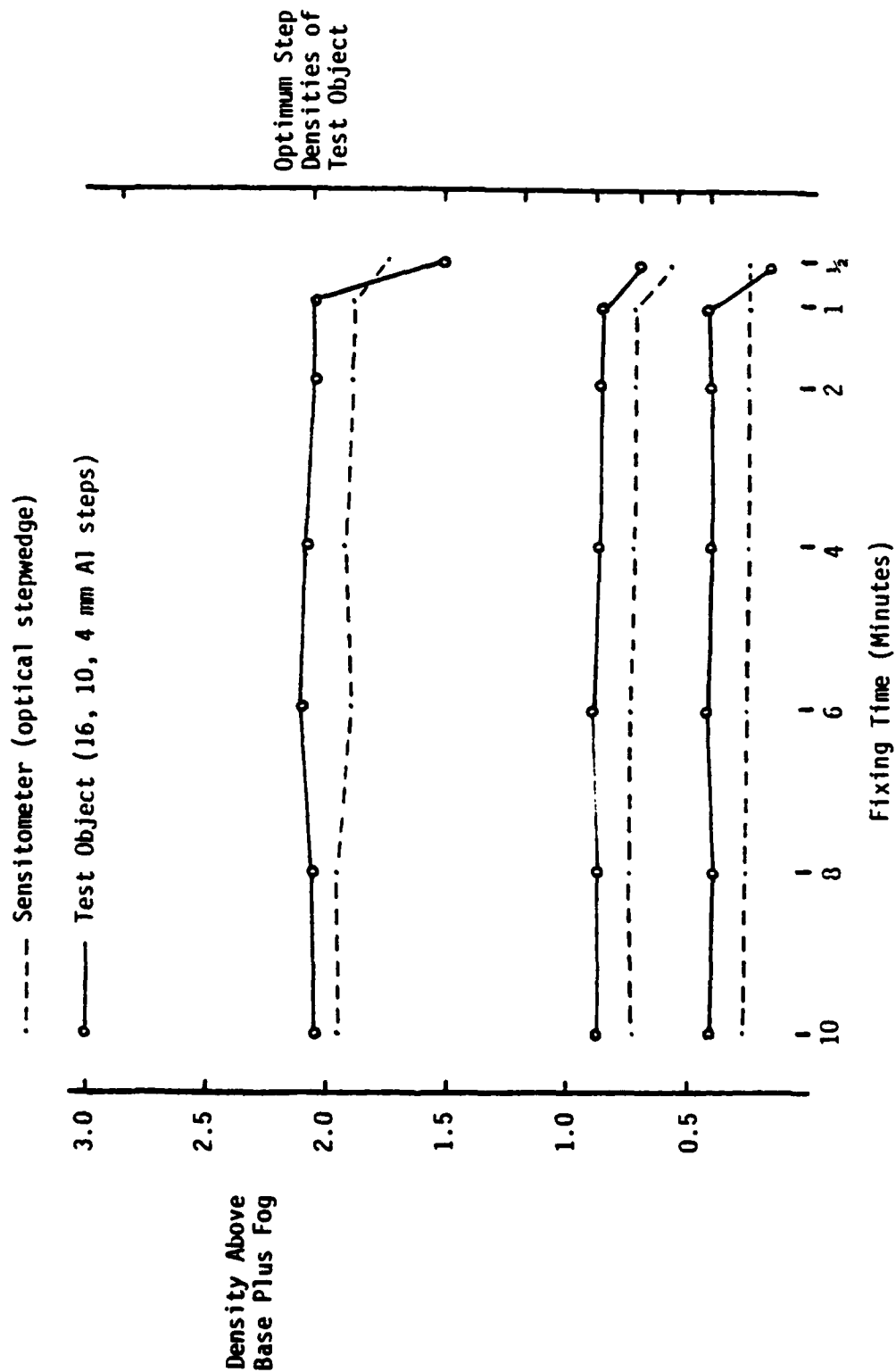
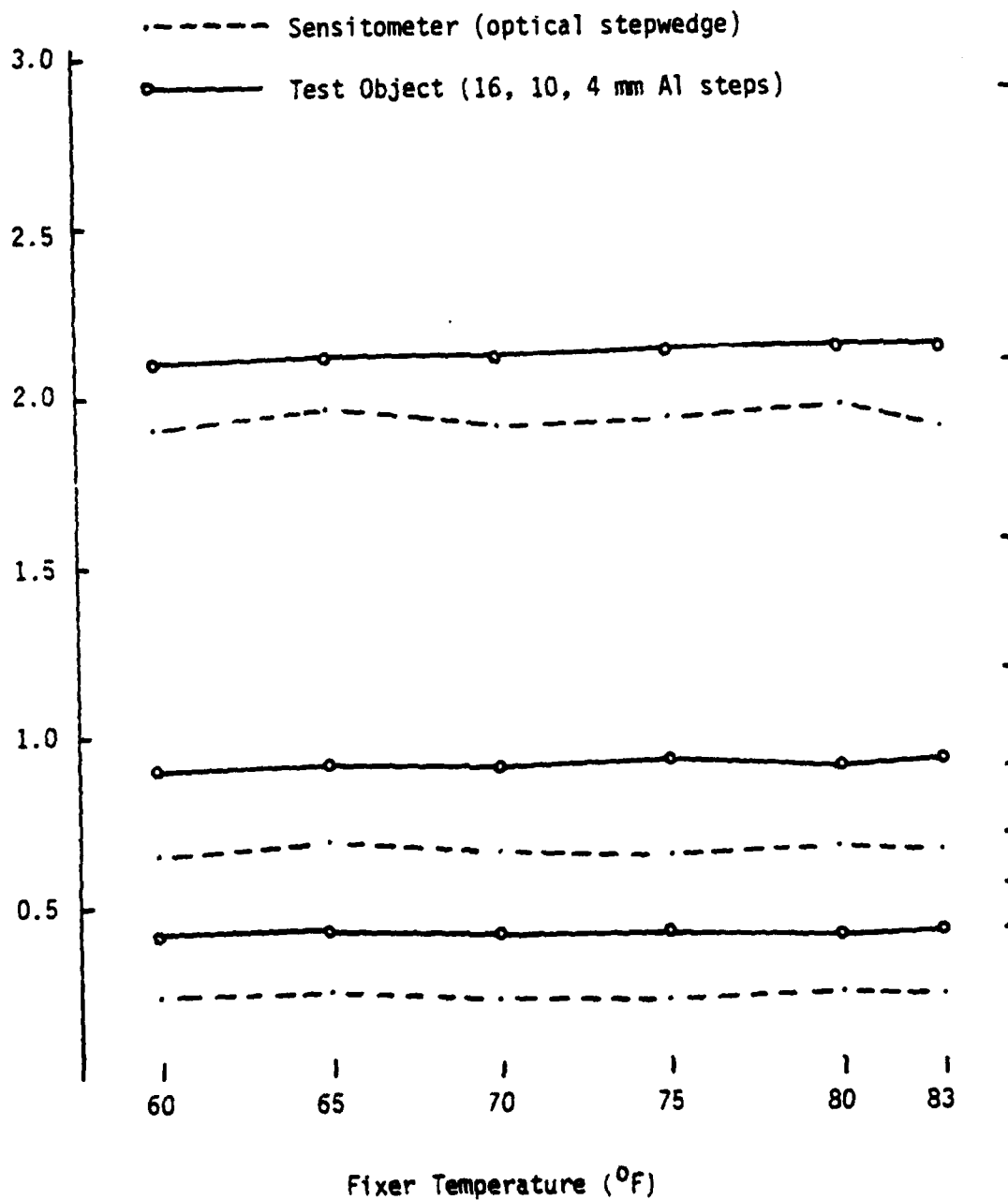


Figure 15

The relationship between radiographic density (less base plus fog) and fixer temperature of sensitometer and test object radiographs of 3 density levels in manual processing

Density Above
Base Plus Fog

Optimum Step
Densities of
Test Object



The data show that the sensitometer and test object radiographs closely paralleled each other. The test object functioned with the same accuracy as the sensitometer in detecting changes in fixer temperature.

Fixer Aging

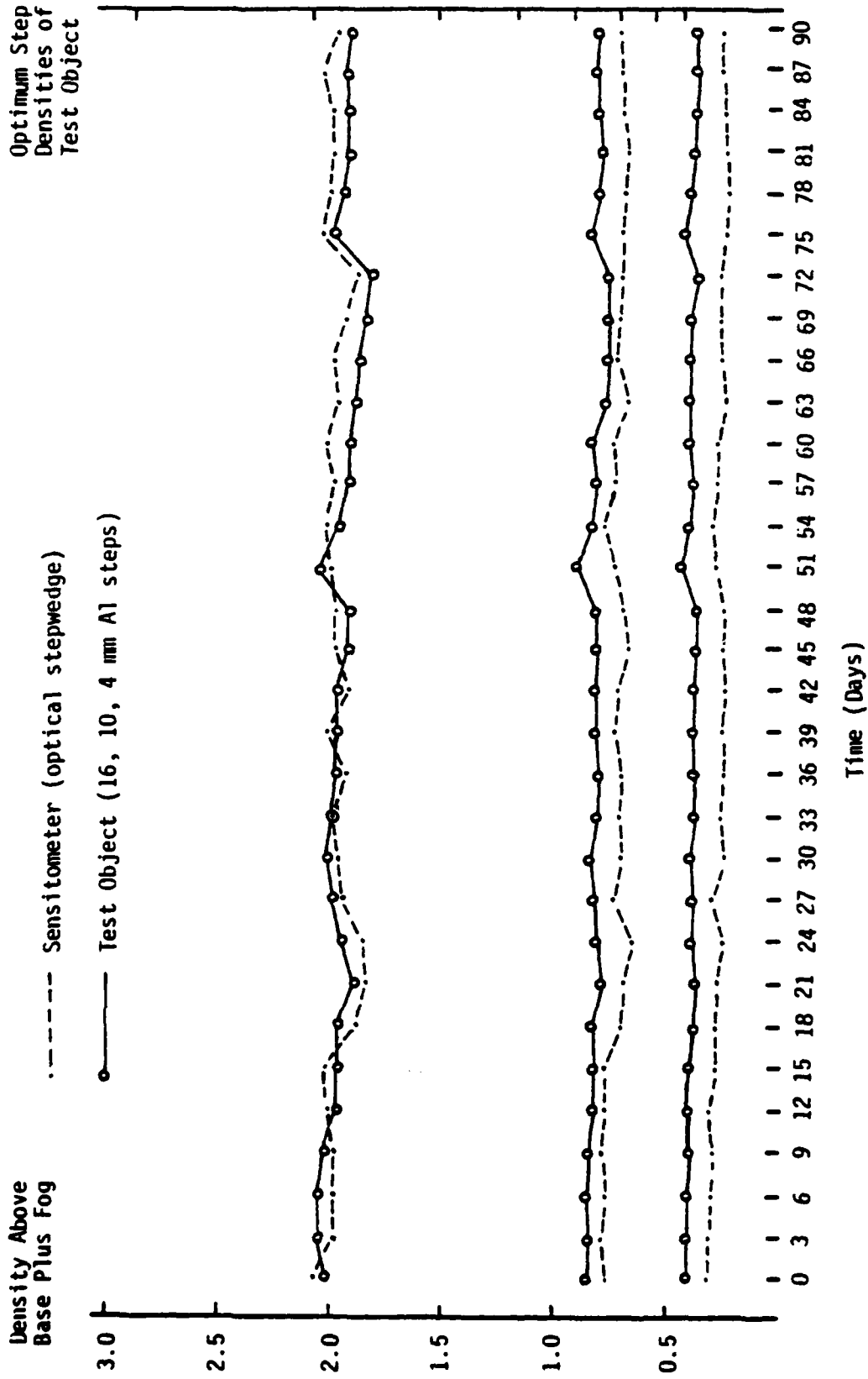
Radiographic density changes were measured with degradation of fixer solution due to time and oxidation. Five of 150 periapical films exposed to x-rays with the test object were processed every 3 days for 90 days. Surface area of the 5-gallon fixer solution was 59 square inches or 11.8 square inches per gallon. The fixer solution was covered throughout the 90-day period with the exception of approximately 30 hours test time.

Figure 16 shows the relationship between density (less base plus fog) and time of sensitometer and test object radiographs of 3 density levels. There was a gradual drop in both the sensitometer and test object densities during the first 24-day period. Fresh developer solution was mixed on the 25th day to bring the density levels back up to the original. Similar results occurred with fresh developer solution mixes on the 37th and 73rd days. Since these developer solution changes brought the density levels back up to the original, the fixer solution was not the cause of the gradual drop in density between fresh developer solution mixes. There was no detectable step density shift due to fixer aging throughout the 90-day period.

Figure 16

The relationship between radiographic density (less base plus fog) and
time of sensitometer and test object radiograph
of 3 density levels in manual processing

()



The sensitometer and test object step densities closely paralleled each other throughout the 90-day period. The parallelism indicates that the test object functioned with the same accuracy as the sensitometer in detecting changes in fixer solution age.

Automatic Processing Variables

A series of independent experiments measured the accuracy of the test object to detect changes in an automatic processor solution concentration, temperature, and chemical activity by depletion and aging. The results are presented separately for each variable.

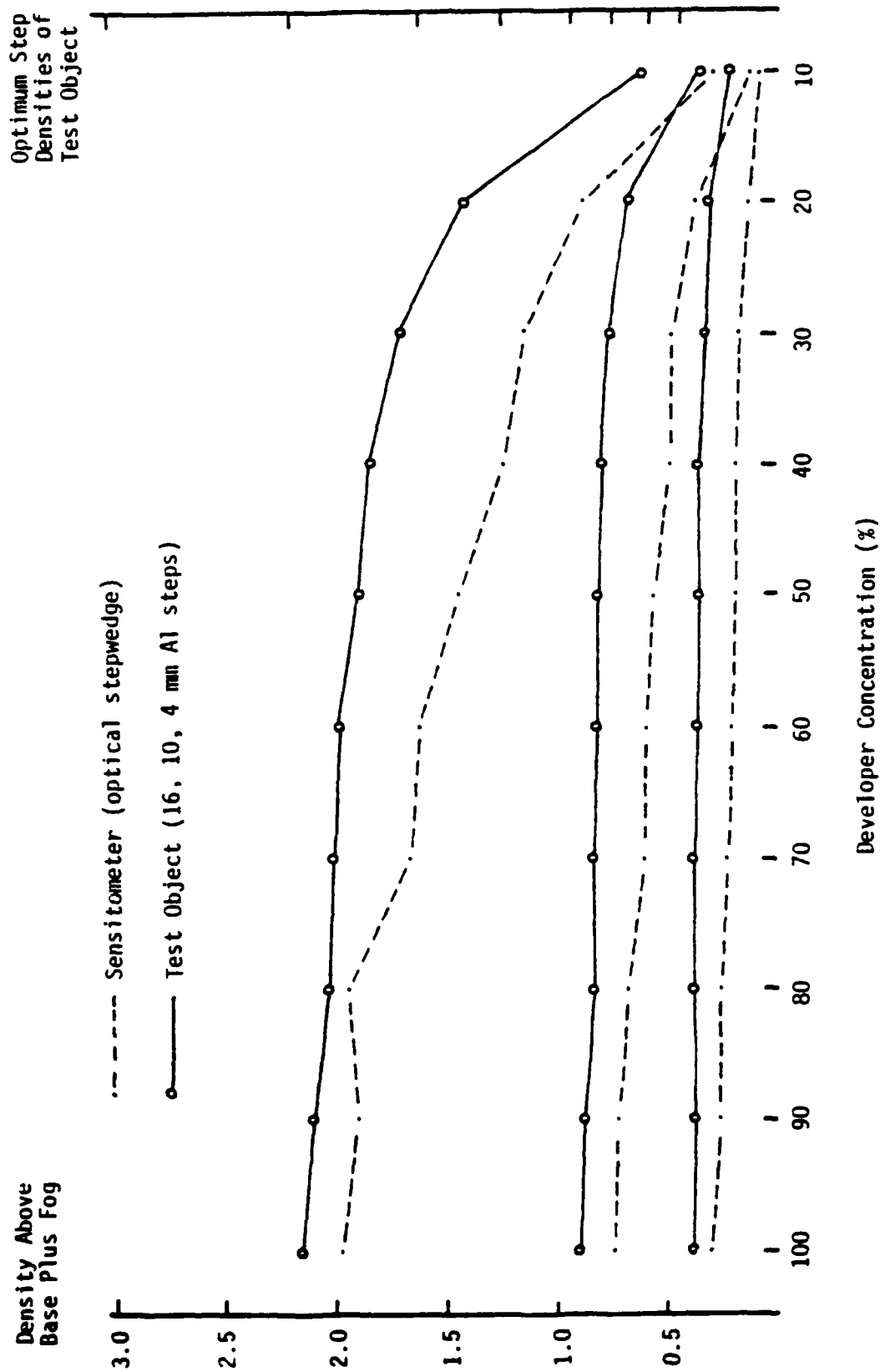
Developer Dilution

Developer solutions were diluted with water from 100% to 10% concentration at 10% increments to measure radiographic density changes of the test object with concentration. All other variables were kept constant.

Figure 17 shows the relationship between density (less base plus fog) and developer solution concentration of test object and sensitometer radiographs. Developer solution concentration of 45% produced a step density shift of approximately 1/2-step lighter in the test object radiographs. A 25% developer concentration produced a step density shift approximately 1 step lighter, while a 15% concentration produced a shift approximately 2 steps lighter.

Figure 17

The relationship between radiographic density (less base plus fog) and developer solution concentration of sensitometer and test object radiographs of 3 density levels for an automatic processor



The data show that the sensitometer and test object step densities closely paralleled each other. The test object functioned with the same accuracy as the sensitometer in measuring or monitoring developer solution dilution.

Developer Temperature Variations

Developer temperature was varied from 60°F to 86°F in 2° increments to measure radiographic density changes of the test object with developer temperature variations. All other variables were kept constant.

Figure 18 shows the relationship between radiographic density (less base plus fog) and developer temperature of sensitometer and test object radiographs of 3 density levels. A temperature of 8° below optimum produced a test object radiograph with less density that had approximately 1/2-step shift in density. An 18° drop in developer temperature produced approximately a 1-step shift in step densities.

The data show that the sensitometer radiographic step densities for all 3 density levels decreased with a steeper slope than the test object step densities as developer temperature decreased.

Developer Aging

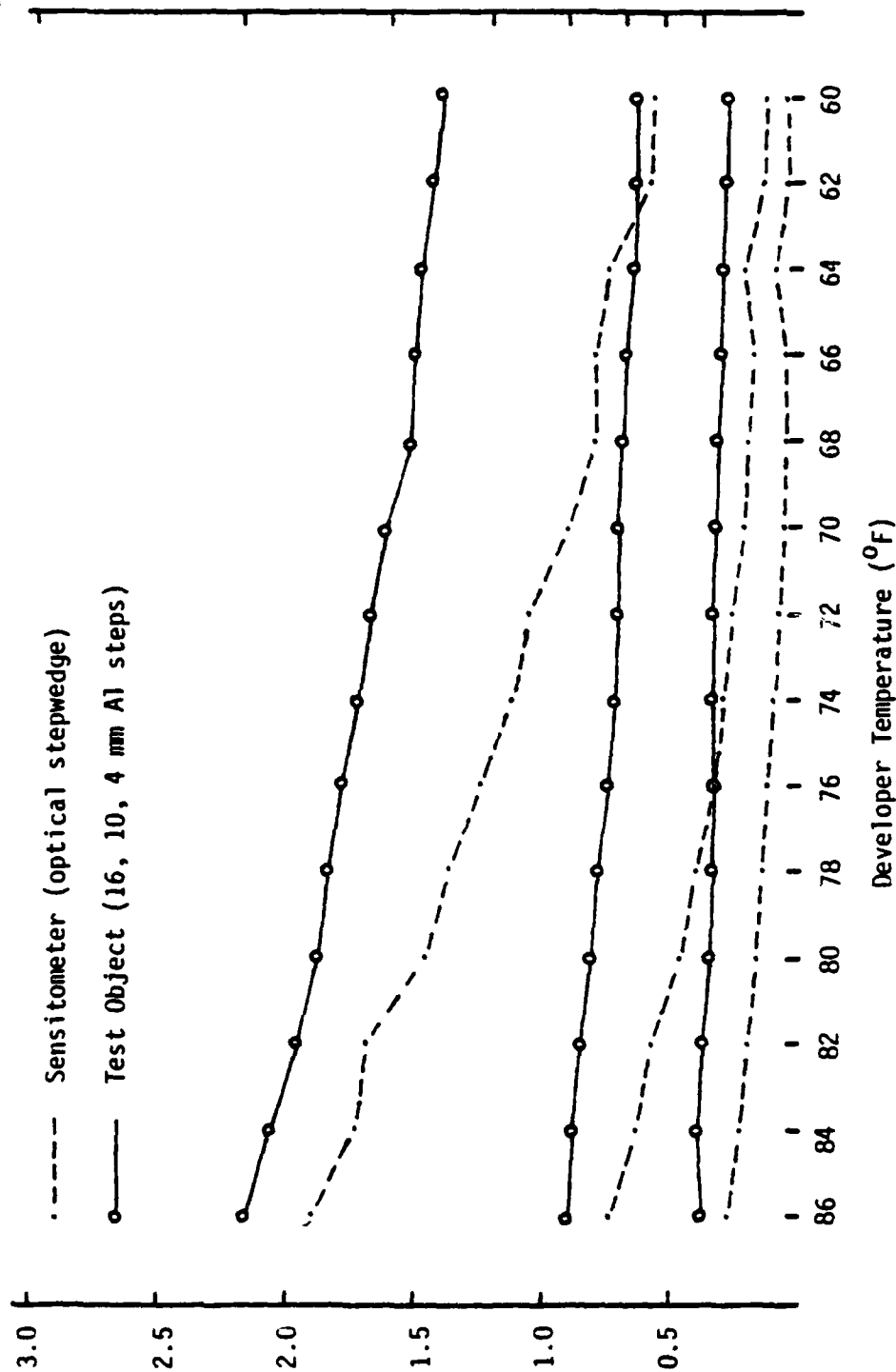
Radiographic density changes were measured with degradation of developer solution due to time. Eighty periapical films were exposed to x-rays with the test object. Five films were processed every other day for 30 days. The

Figure 18

The relationship between radiographic density (less base plus fog) and development temperature of sensitometer and test object radiographs of 3 density levels for an automatic processor

Optimum Step
Densities of
Test Object

Density Above
Base Plus Fog



surface area of the 2-quart processing tank was 36.4 square inches or 72.8 square inches per gallon.

Figure 19 shows the relationship between radiographic density (less base plus fog) and time of sensitometer and test object radiographs of 3 density levels. Developer solution degradation during the first 10 days produced periapical radiographs with less density (approximately 1/2-step density shift). Degradation during the first 16 days produced approximately a 1-step density shift. Approximately a 2-step density shift resulted from 18 days of degradation, and approximately a 3-step density shift was produced after 22 days.

Developer Chemical Depletion

Periapical films were exposed to x-rays with the phantom and processed in 40 film increments to measure radiographic density changes due to chemical depletion of the developer solution. Each set of 40 periapical films was processed in 1/10 gallon of developer.

Figure 20 shows the relationship between radiographic density (less base plus fog) and number of periapical films processed of sensitometer and test object radiograph of 3 density levels. There was no step density shift in the test object radiographs after 480 periapical films and 84 test films were processed by the developer solution. This number of films extrapolates linearly by volume to 2,400 periapical and 420 test films processed by 2 quarts of developer

Figure 19

The relationship between radiographic density (less base plus fog) and time of sensitometer and test object radiographs of 3 density levels for an automatic processor

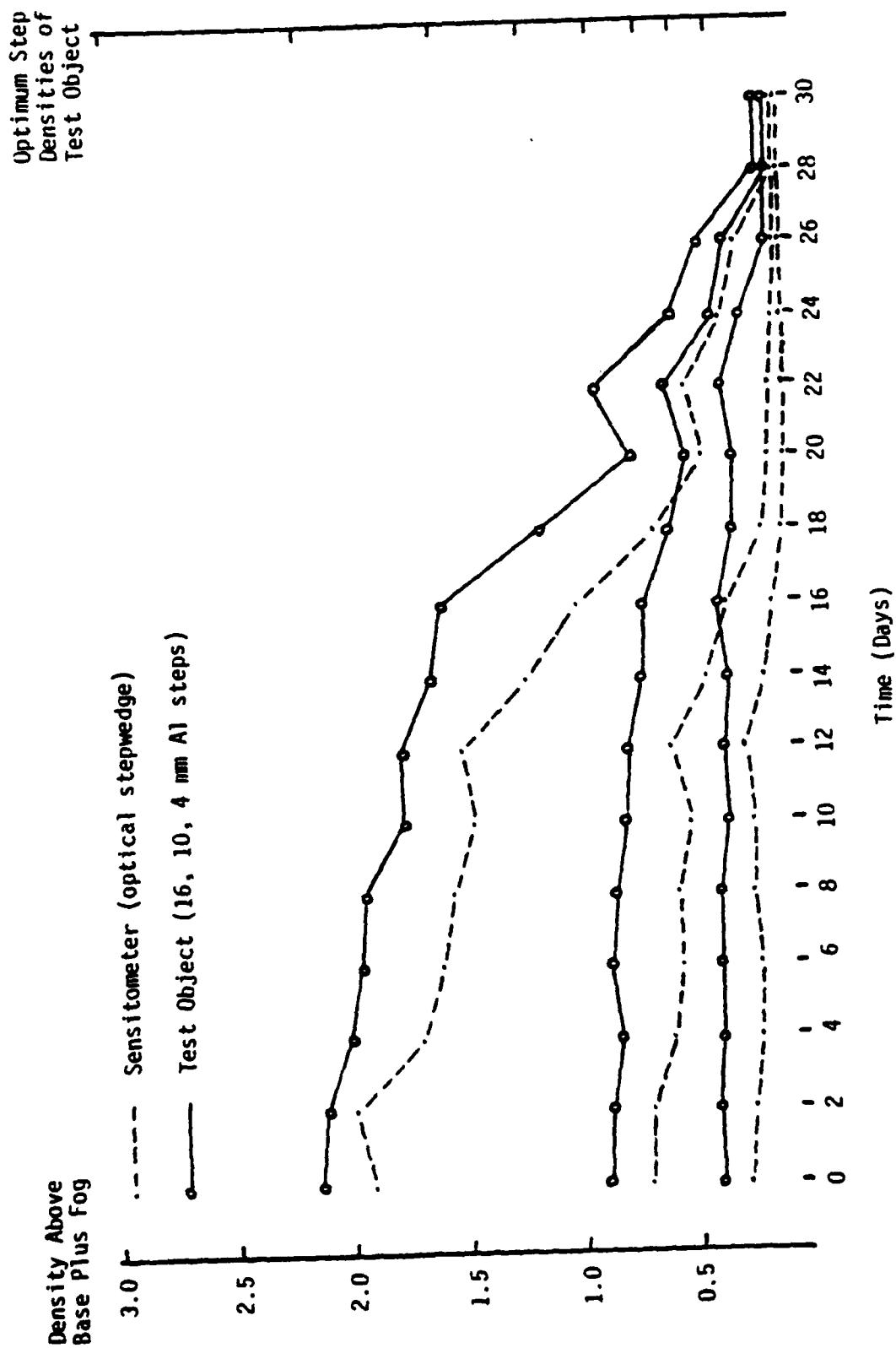
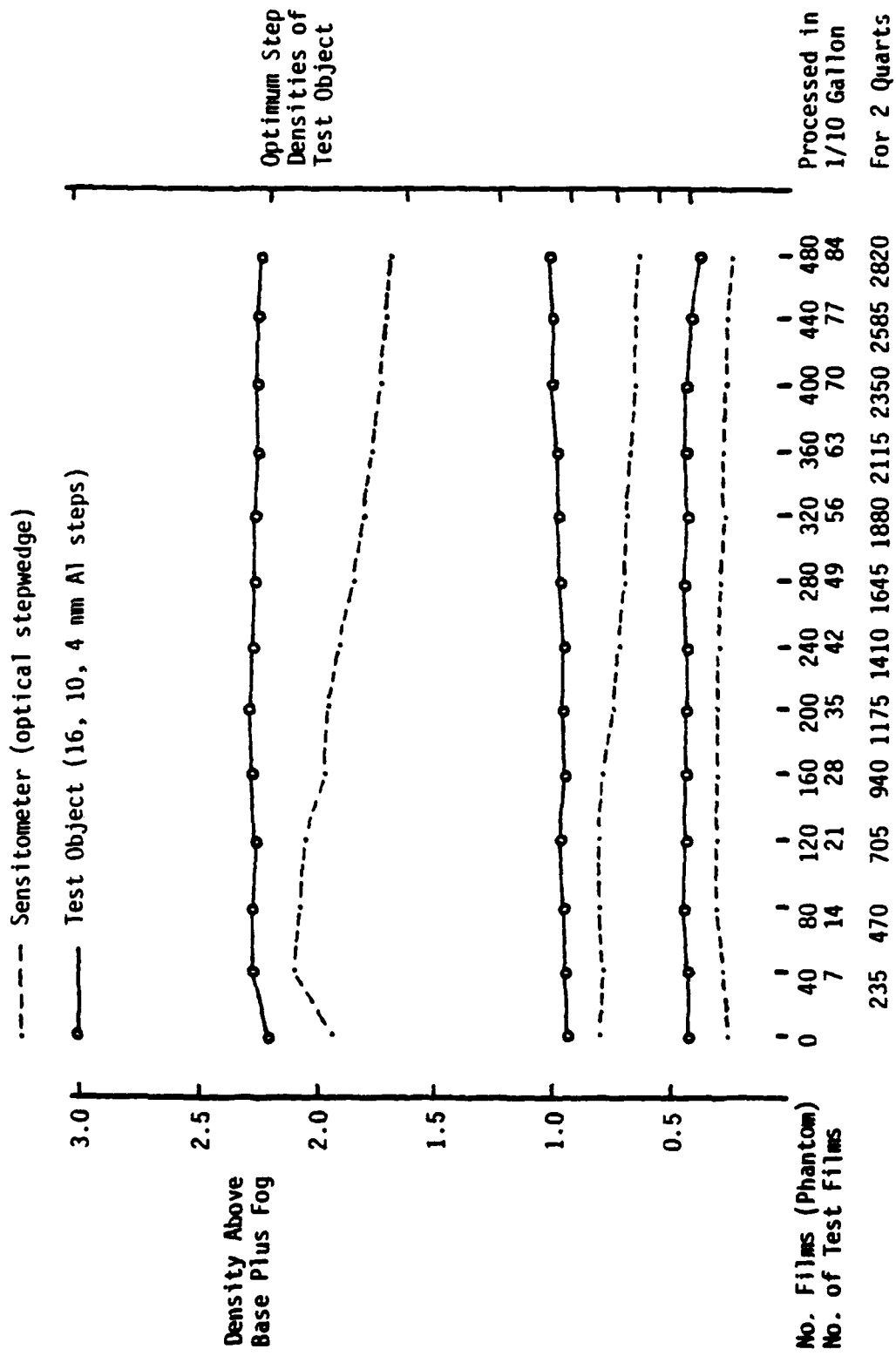


Figure 20

The relationship between radiographic density (less base plus fog) and number of periapical films processed of sensitometer and test object radiographs of 3 density levels for an automatic processor



solution normally used by the automatic processor. The data show that the sensitometer step densities gradually declined with increasing numbers of processed periapical films while the test object step densities showed no change.

Fixer Dilution

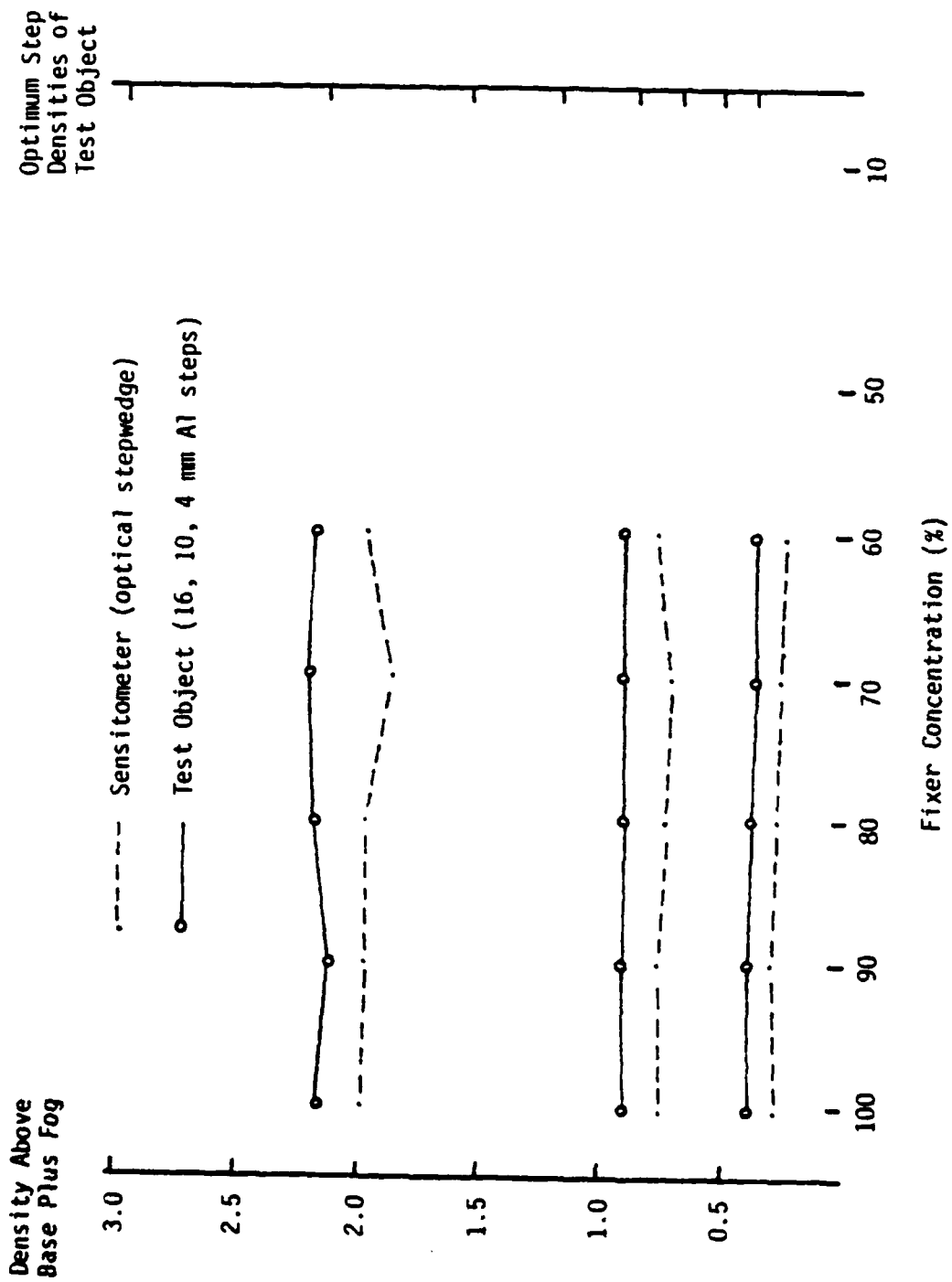
Fixer solution was diluted with water from 100% to 10% concentration at 10% increments to measure radiographic density changes of the test object with fixer concentration. All other variables were kept constant.

Figure 21 shows the relationship between radiographic density (less base plus fog) and fixer solution concentration of sensitometer and test object radiographs. There was no density change in sensitometer or test object radiographic step densities with concentration changes from 100% through 60%. Below 60% all test object radiographs were unfixed (residual silver halide crystals remained in the emulsion). Sensitometer films were fixed with solutions concentrations as low as 30%. Below a 30% concentration the sensitometer radiographs were unfixed.

The data show that the sensitometer and test object step densities were closely parallel through a fixer concentration of 60%. The test object functioned with the same accuracy as the sensitometer in measuring or monitoring fixer dilutions as low as a 60% concentration.

Figure 21

The relationship between radiographic density (less base plus fog) and
fixer concentration of sensitometer and test object radiographs
of 3 density levels for an automatic processor



Fixer Temperature Variations

Fixer temperature was varied from 60°F to 85°F in 5° increments, and at 86°F, to measure radiographic density changes with fixer solution temperature variations. All other variables were kept constant.

Figure 22 shows the relationship of radiographic density (less base plus fog) and fixer temperature of sensitometer and test object radiographs of 3 density levels. There was no step density change in sensitometer or test object radiographic step densities as fixer temperature decreased from 86°F to 80°F. There was no step density change in sensitometer step densities between 86°F and 60°F. Below 80°F the test object radiographs were unfixed.

The data show that the sensitometer and test object radiographic step densities were closely parallel between 86°F and 80°F. The test object functioned with the same accuracy as the sensitometer in detecting fixer solution temperature variations between 86°F and 80°F.

Fixer Aging

Radiographic density changes were measured with degradation of fixer solution with time. Five of 80 periapical films exposed to x-rays with the test object were processed every other day for 30 days. Surface area of the 2-quart processing tank was 36.4 square inches or 72.8 square inches per gallon.

Figure 22

The relationship between radiographic density (less base plus fog) and fixer solution temperature of sensitometer and test object radiographs of 3 density levels for an automatic processor

Density Above
Base Plus Fog

Optimum Step
Densities of
Test Object

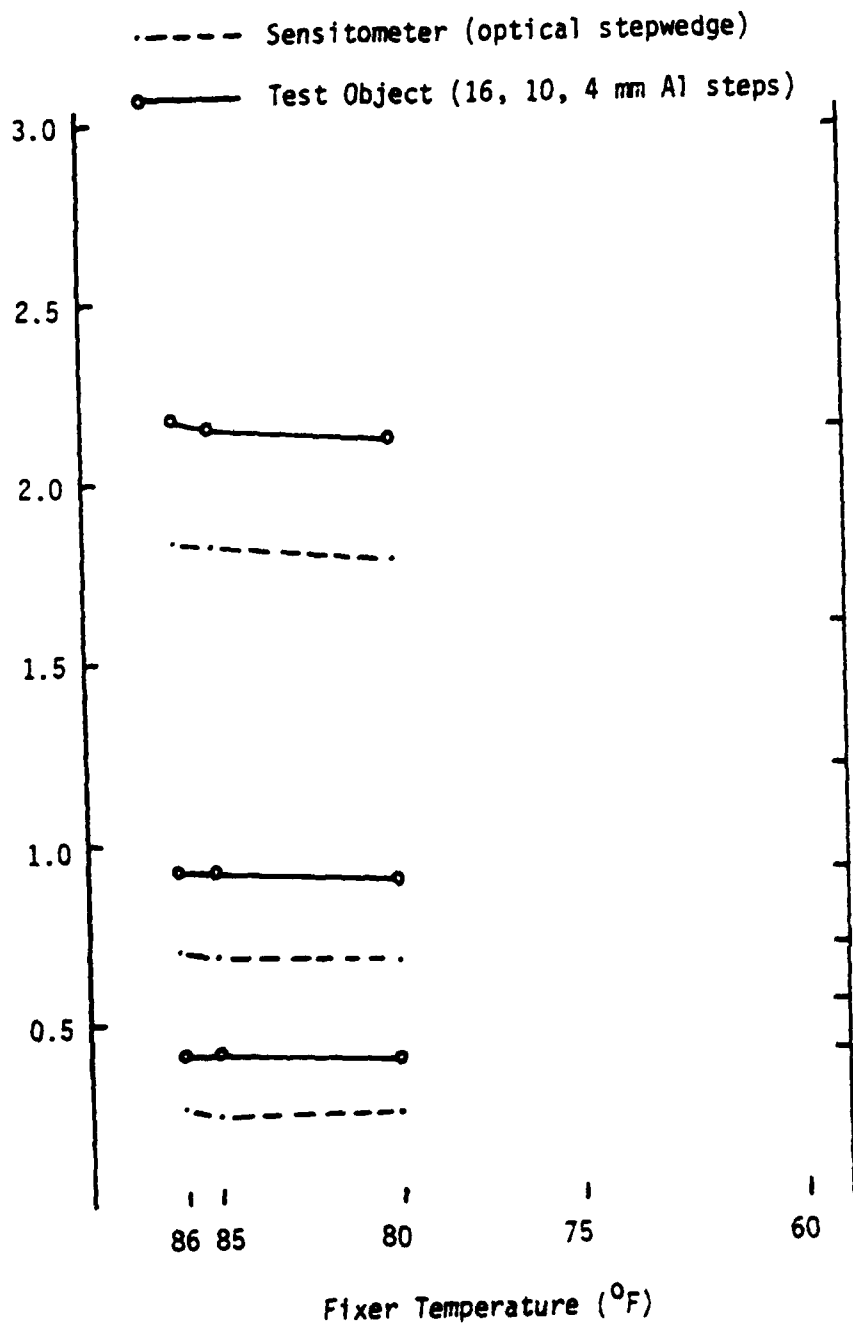


Figure 23 shows the relationship between radiographic density (less base plus fog) and time of sensitometer and test object radiographs of 3 density levels. There was no radiographic step density shift in sensitometer or test object radiographs throughout the 30-day period.

The data show that the sensitometer and test object radiographic step densities were closely parallel throughout the 30-day period. The test object functioned with the same accuracy as the sensitometer in evaluating the condition of the fixer solution over a 30-day period.

X-Ray Machine Output Changes

Two independent experiments measured the accuracy of the test object to detect changes in x-ray machine output. One experiment varied kVp with all other variables kept constant. The other varied mAS with all other variables kept constant. The results of the 2 studies will be presented separately.

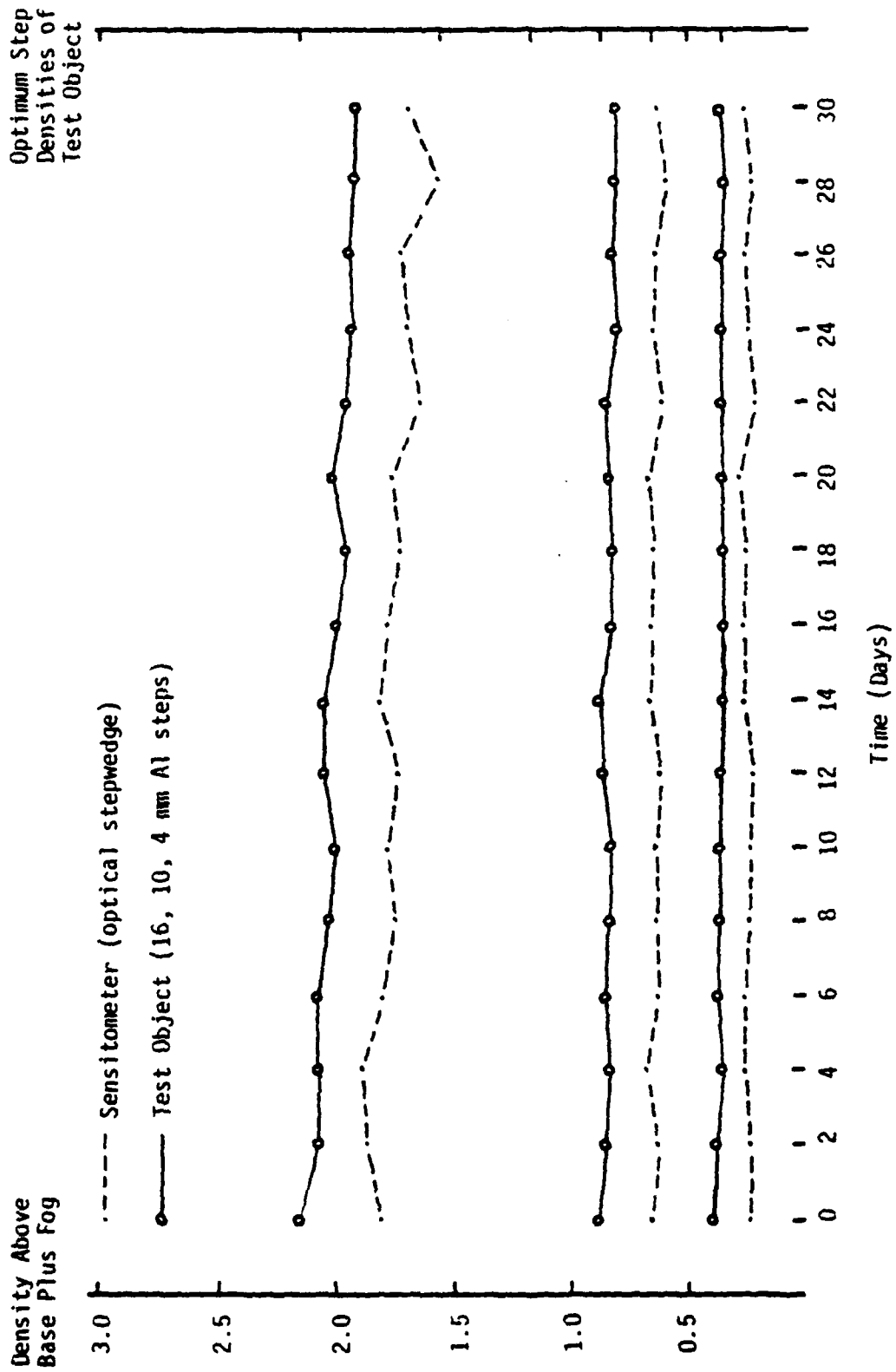
kVp Variations

kVp was varied from 50 to 90 at 5-kVp increments to determine step density changes in the radiographs of the test object with kVp variations. The half value layer of the 9 setting used was measured and found to be 1.75, 1.80, 1.90, 2.0, 2.15, 2.30, 2.50, 2.70, and 3.0 mm aluminum

Figure 23

The relationship between radiographic density (less base plus fog) and time of sensitometer and test object radiographs of 3 density levels for an automatic processor

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equivalent. Exposure time was 1 second at 10 mA for each kVp setting used.

Figure 24 shows the relationship between density (less base plus fog) and kVp for test object radiographs of 3 density levels. The sensitometer received the same amount of light energy for each processing session, and the radiographic step densities showed no change throughout the experiment, indicating constant processing. As the kVp increased, the test object radiographic step densities of all 3 density levels increased. A change of 5 kVp produced approximately a 1/2-step density shift in the test object radiographs. A 10 kVp change produced approximately a 1-step density shift, while a 15 kVp change produced approximately a 2-step density change.

mAs Variations

Radiographic density changes were measured with variations in exposure times from 3 to 300 impulses at 70 kVp and 10 mA, and also at 70 kVp and 15 mA with the kVp indicator in the same position on the kVp meter. Figure 25 shows the relationship between radiographic density (less base plus fog) and exposure time of test object radiographs of 3 density levels made with 70 kVp and 10 mA. Figure 26 was made with 70 kVp and 15 mA with the kVp indicator in the same position on the kVp meter. The sensitometer radiographic step densities showed no change in both figures, indicating constant

Figure 24

The relationship between radiographic density (less base plus fog) and
kVp of test object radiographs of 3 density levels

Density Above
Base Plus Fog

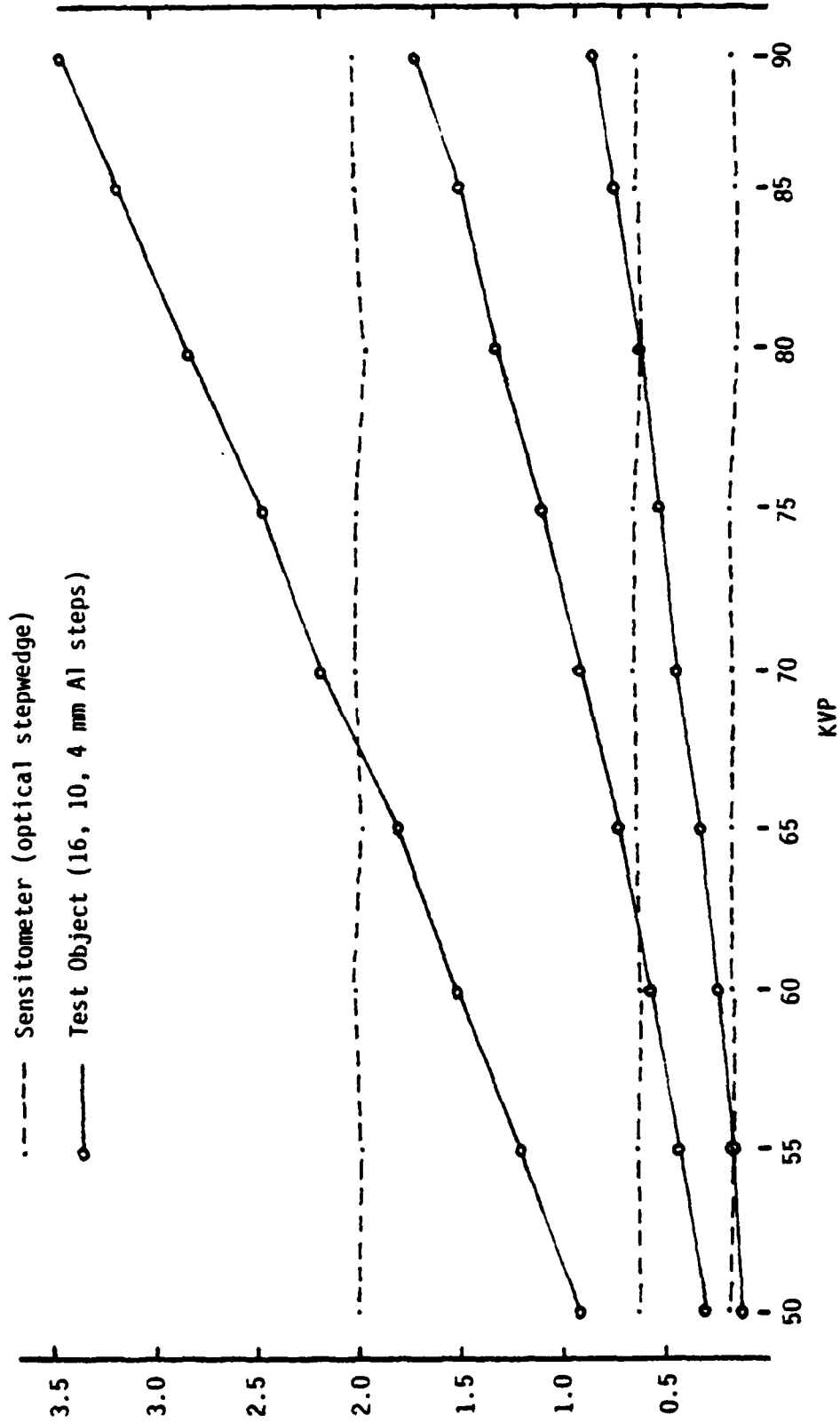


Figure 25

The relationship between radiographic density (less base plus fog) and
impulses with 70 kVp and 10 mA of test object radiographs
of 3 density levels

Optimum Step
Densities of
Test Object

Density Above
Base Plus Fog

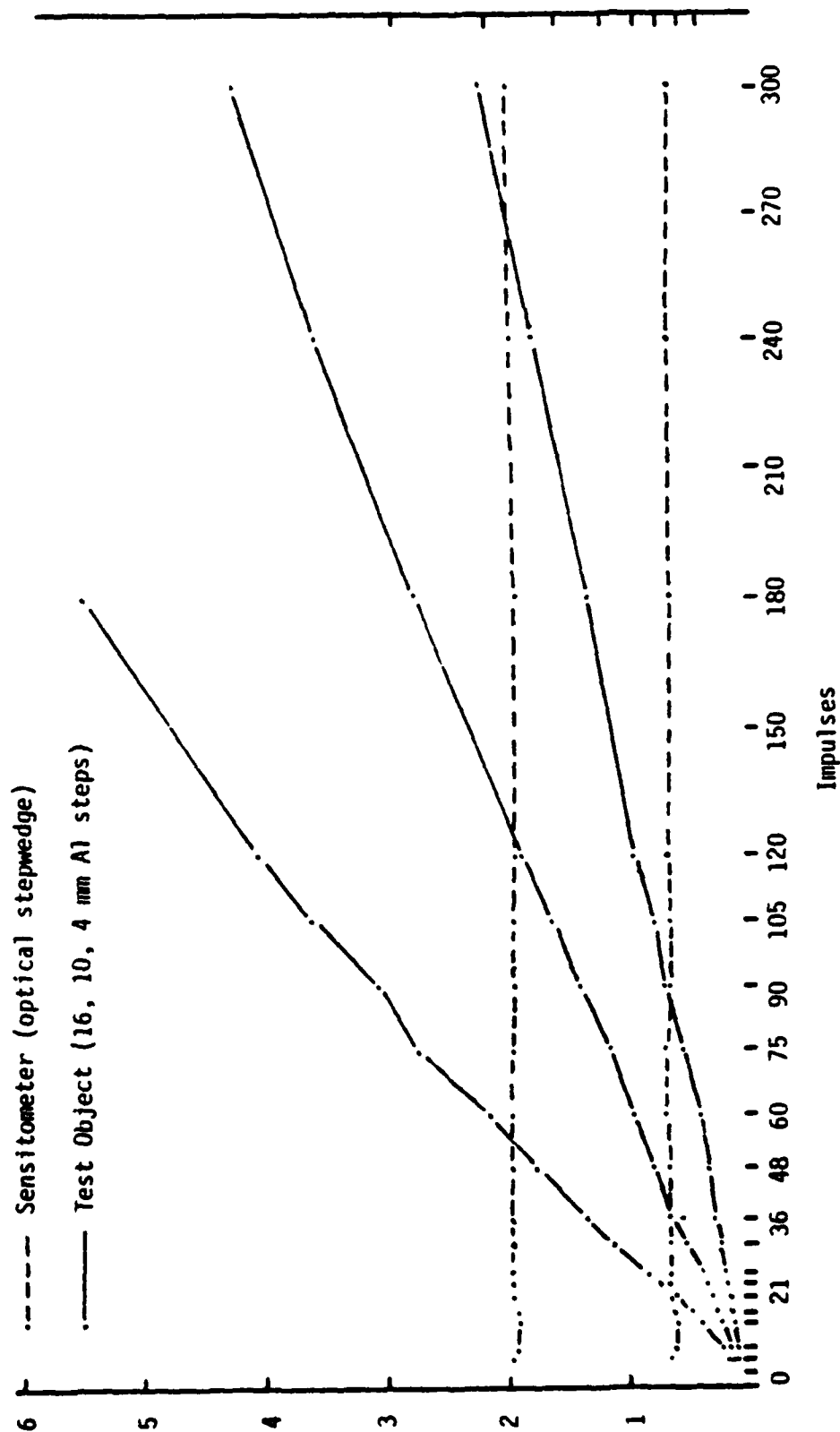
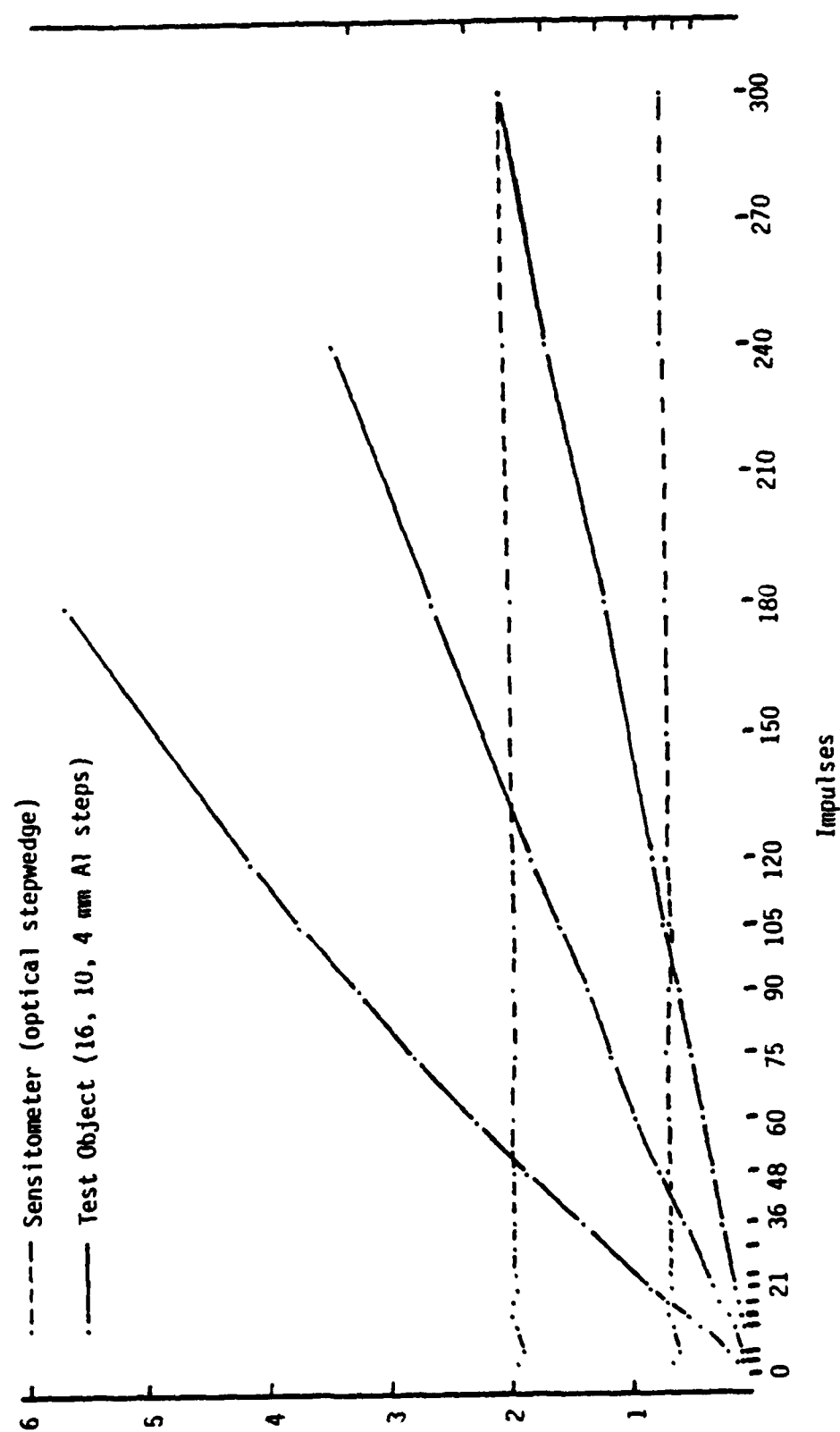


Figure 26

The relationship between radiographic density (less base plus fog) and impulses with 70 kVp and 15 mA of test object radiographs of 3 density levels

Optimum Step
Densities of
Test Object

Density Above
Base Plus Fog



processing. In both Figures 25 and 26, a 15-impulse variation above 60 impulses produced approximately a 1/2-step density change in test object radiographs while a 30-impulse variation produced approximately a 1-step shift in step densities. In both Figures 25 and 26 a change of 15 impulses below 60 impulses produced approximately a 1-step density change in the test object radiographic step densities, while a 30-impulse change produced approximately a 2-step density shift.

DISCUSSION

The results were analyzed to determine the effectiveness of the test object as used in a dental school quality assurance test (Manson-Hing, 1982). The objective of the stepwedge test is to detect both x-ray machine and film processing changes prior to the loss of clinical diagnostic quality. The range of clinically acceptable densities that dentists use will be discussed first because the amount of radiographic change the test must depict is directly related to the clinically acceptable radiographic density range. The effectiveness of the aluminum stepwedge to reflect x-ray machine output changes will be discussed next because it shows the amount of change that the stepwedge test can identify in terms of film exposure and the clinically acceptable density range. Next in the discussion will be the amount of latent image fading that occurs over the time the stepwedge test is expected to be used; this will be followed by the test's sensitivity to detect manual and automatic film processing changes. Finally, the error involved with the task of dental auxiliaries to match visually radiographs of similar density steps will be discussed.

Clinically Acceptable Density Range

Radiographic density increases with the number of impulses used for a given kVp and mA combination. Data from Figure 6 show that dentists will accept radiographs having densities produced with exposures that are approximately 250% above and 500% below the number of impulses that produce the most acceptable radiographic density. Optimum density of the stepwedge image used with the stepwedge test is obtained with an exposure of 60 impulses. Known exposure factors allow conversion of the clinically acceptable density range into numbers of step density shifts in periapical radiographs of the test object.

Figure 25 shows that when the 10 mm-step of the test object is exposed with 150 impulses (a 250% increase in the optimum number of 60) a density of 2.3 (above base plus fog) is produced, and when the 10 mm-step is exposed with 12 impulses (a 500% decrease in the optimum number of 60), a density of 0.2 (above base plus fog) is produced. Thus, the clinically acceptable density range for the 10 mm-step is 2.1 (0.2 to 2.3 density above base plus fog). The 4 mm-step of the test object produces a density range of 4.35 (0.4 to 4.75 density above base plus fog). The radiographic densities of the 8 steps of the test object exposed with the optimum number of 60 impulses produces a density range of 2.51 between the 2 mm- and 16 mm-steps (0.44 to 2.95 density above base plus fog) as indicated on the ordinate of Figure 25.

The 2.1 density range of the 10 mm-step due to acceptable film exposure variation is less than the 2.51 range of the 8 steps of the test object, and is a range of more than 7 but less than 8 step densities of the wedge. The 4.35 density range of the 4 mm-step due to film exposure variation is much greater than the 2.51 density range of the 8 steps of the test object, and is a range much greater than 8 steps.

The stepwedge test uses a shift in the density of a single step of 2 step densities from the same step in a reference stepwedge image of 8 steps to detect x-ray machine or processing changes that need correction. Such changes would thus be detected long before radiographs made under incorrect conditions become unacceptable to the average dentist.

X-Ray Machine Output Changes

X-ray machine output increases with the number of impulses used for a given kVp and mA combination. Figure 25 shows that density of the 10 mm-step of the test object changes 2 step densities with approximately a 50% increase or decrease in the number of impulses. The stepwedge test sensitivity allows a variation of approximately 30 impulses above or below a 60 impulse optimum before a 2-step change occurs, and is a detection at approximately 25% of the 7-8 available step density range. Similar changes occur with the 4 mm- and 16 mm steps of the test object.

Data in Figure 26 were based upon output of the x-ray machine at 15 mA with the kVp indicator in the same position on the kVp meter as was used with 10 mA (Figure 25). Both figures reveal essentially the same graphs, showing the same degree of sensitivity to impulse variations, irrespective of the use of 10 mA or 15 mA. Thus, accidental use of 15 mA instead of 10 mA with the kVp indicator in the same position would not be detected by the stepwedge test. A change in the x-ray machine setting from 10 mA to 15 mA with the kVp meter in the same position does not change the output. An increase in mA increases the number of available electrons at a given tube potential difference, but the efficiency of short wavelength photon production decreases. Without a corresponding increase in tube potential to offset the decrease in efficiency, x-ray machine energy output remains the same. The machine design requires the operator to increase the kVp with an increase in mA.

Step densities of the test object image increase with a change of kVp. McLemore (1981) stated that the accuracy of the kVp set on the control panel can have a dramatic effect on the overall quality of the finished radiograph. She stated that with use of the Wisconsin test cassette an accuracy of plus or minus 2 kVp can be detected with densitometric matching of density steps, while an accuracy of plus or minus 4 kVp can be detected with visual matching of the density steps. Gould and Gratt (1983) detected a 5 kVp change with their quality control system using a sensitometer for film

exposure and evaluated density changes visually. The present stepwedge test, if used with a densitometer, would detect a 5 kVp variation with a 1/2-step density change (figure 24). The objective of the stepwedge test does not require a 2 to 5 kVp detection since its purpose is to detect changes only prior to the loss of clinical diagnostic quality. The stepwedge test, which uses neither densitometer nor sensitometer, detects approximately a 15 kVp variation by visual detection of a 2-step density change in the stepwedge image. In addition, the need to detect changes in kVp may be of little importance in dental radiography. In a survey of 195 private dental offices in Jefferson County, Alabama, Wuehrmann, Jamison, and Manson-Hing (1963) found processing techniques to be of greater variability than x-ray machine output changes. Gibbs, Crabtree, and Johnson (1977) also found that the incidence of inadequate processing techniques was surprisingly high and was a major cause of unnecessary patient exposure. Gould and Gratt (1983) stated that the majority of film quality problems in dental radiography are a result of poor film processing. Inadequate processing techniques are thus more likely to be a problem than kVp variability in clinical dentistry.

Since kVp variations are less likely to be a problem than processing techniques, the importance of detecting kVp changes diminishes, especially in view of the time and expense needed to detect small changes. Densitometers and

sensitometers each cost hundreds of dollars and are time consuming for use by the average dentist. Gould and Gratt (1983) stated that clinical testing of their system indicated that the daily monitoring system required too much time and that dentists were too busy to be intimately involved with their system. They stated that a possible solution was to shorten the procedure by eliminating the use of the sensitometer. The stepwedge test was designed to avoid costly, complex, and time consuming instrumentation.

Latent Image Fading

Fading of the latent image of medical radiographic films has been known for many years. The amount of fading of the latent image in dental films was a consideration investigated in this study.

McLaughlin and Ehrlich (1954) studied latent image fading of 6 different films with storage time during the first 6 days after exposure. They found various amounts of latent image fading due to variables such as time, atmospheric chemicals (O_2), temperature, emulsion type, dose rate, processing type, grain size, size of silver speck development centers, and humidity. The Eastman Kodak Company (1984) stated that heat and humidity are the 2 factors that most often affect the aging of photographic films, and that these elements can be controlled to some degree by sealing films in moisture vapor-resistant containers.

Polanski and Smith (1968) stated that non-screen film exposed to x-rays with an aluminum stepwedge was almost useless in film processing control. They therefore used sensitometric film strips pre-exposed to light for film processing control. They found that aged pre-exposed film strips were not as sensitive to processing changes as freshly exposed film strips, and concluded that 3-month-old strips were of little value in day-to-day control of developing variations. They offered no explanation as to why aged film strips were less sensitive.

Results from Figure 5 show that no densitometrically detectable latent image fading occurred within 90 days after exposure of dental films to x-rays when stored in a cool, dry lead container away from x-rays. These results are reinforced by the investigation into radiographic density changes measured with degradation of fixer solution by aging (Figure 16). The results show no measurable step density shift at the end of the 90-day period. Relative to the 7-8 available density steps of the stepwedge test, the amount of latent image fading, if any, is extremely small and may be ruled out as a variable detrimental to the stepwedge test performance.

The present results are inconsistent with the conclusions of McLaughlin and Eherlich (1954) and Polanski and Smith (1968). Neither McLaughlin and Eherlich nor Polanski and Smith showed the magnitude of latent image fading over a protracted period of time, and neither study indicated the

use of dental films nor related their findings to the clinical situation. The lack of latent image fading in this study may be because the effect of heat, humidity, and atmospheric chemicals were minimized since the films used were stored in a cool, dry place and dental film packets are especially designed to protect the film from moisture. Polanski and Smith did not state how their pre-exposed film strips were stored. The objective of their quality control system was to check only processing, but they did not state the magnitude of changes they wished to detect. An objective of the stepwedge test is to check processing, but only relative to the loss of clinical diagnostic quality. The magnitude of changes the stepwedge test is to detect is a shift of 2 density steps relative to 7-8 available density steps. Thus, latent image fading does not affect the stepwedge test if films are properly stored.

Film Processing Variables

A total of 16 automatic and manual film processing variables were investigated in this study. A summary of these results shown in Figures 5-20 is presented in Table 1. The summary shows film processing changes that produced 1-, and 1/2-step density shifts of the 10 mm-step of the test object as measured on the reference radiograph. Table 1 also shows the optimum film processing conditions and experimental range tested for each processing variable.

Table 1

Summary of results for manual and automatic film processing changes producing 2-, 1- and 1/2-step density shifts in periapical radiographs of the 10 mm-step of the test object as measured on the reference radiograph.

Processing Variable	Optimum and Experimental Range Tested	Change to Produce a Density Shift in the 10mm Aluminum Step of the Test Object		
		2 step	1 step	1/2 step
MANUAL PROCESSING				
Developer Dilution	100% 100% to 10% concentration	85%	70%	40%
Development Time	4 1/2 min. 1-8 minutes	>+3 1/2 minutes	+2 1/2 minutes	+1 1/2 minutes
Development Temperature	70°F 60°F to 83°F	-	>+13°F	+10°F
Developer Aging	0 days 0-90 days	>90 days	63 days	36 days
Developer Chemical Depletion	0 films 0-25,600 films (5 gal.)	-	>25,650 films	22,800 films
Fixer * Dilution	100% 100% to 10% concentration	>80%*	>80%*	>80%*
Fixing* Time	10 minutes 1/2 to 10 minutes	>9* minutes	>9* minutes	>9* minutes
Fixing Temperature	70°F 60°F to 83°F	-	-	>13°F
Fixer Aging	0 days 0-90 days	-	-	>90 days
AUTOMATIC PROCESSING				
Developer Dilution	100% 100% to 10%	85%	75%	50%
Development Temperature	86°F 60°F to 86°F	>26°F	26°F	10°F
Developer Aging	0 days 0-30 days	20 days	16 days	10 days
Developer Chemical Depletion	0 films 0-2,820 films (2 qts.)	-	-	>2,820 films
Fixer * Dilution	100% 100% to 10% concentration	>40%*	>40%*	>40%*
Fixing Temperature	86°F 60°F to 86°F	>6°F	>6°F	>6°F
Fixer Aging	0 days 0-30 days	-	-	>30 days

* Films not cleared

An overview of Table 1 reveals that there is an extremely wide latitude for processing conditions under which clinical dental radiographs can be made. In other words, the magnitude of film processing change necessary to produce 2-, 1-, and 1/2-step density shifts in periapical radiographs of the test object is great. The clinical implication is that very great changes in film processing conditions must occur before clinical diagnostic radiographic quality degrades beyond the 7-8 step density range that dentists will accept. The clinically acceptable density range (Figures 6 and 25) shows that a 2-step density shift of the 10 mm-step of the test object is approximately 25% of the available 7-8 step density range. Data in Figure 6 are based upon the evaluations of 20 dentists. Individual dentists may use a smaller density range between marginally acceptable light and dark radiographs. They may thus desire a more narrow range of detection, and this could be accomplished by using a 1-step density shift of a particular step instead of a 2-step shift. A 1-step shift would be a detection at approximately 12.5% of the available 7-8 step densities. An alternate method of narrowing the range of detection or increasing the sensitivity of the test could be to double the number of steps on the test object.

There were 7 fixer variables tested. Four produced films that were not completely cleared. For example, fixer dilution up to 80% with manual processing showed films that were completely cleared, but dilution greater than 80%

produced films that were not completely cleared and the partial clearing was visually detectable. No attempt was made in this study to determine the effect on archival quality of any films from fixer solution changes. A reduction in fixer solution temperature of greater than 6°F in the automatic processor produced films that were not completely cleared. While most studies indicate fixing to be non-temperature sensitive, the lack of film clearing with a lowering of 6°F may be due to a slight reduction of chemical activity. This small activity loss may be observable due to the highly concentrated fixer and a very short fixing time used by the automatic processor. The other 3 fixer solution variables tested showed less than 1/2-step density shifts over the entire range tested. Therefore, for the 7 fixer conditions tested, no increase in sensitivity of the stepwedge test to fixer solution changes would detect small fixer solution changes affecting film clearing for either manual or automatic film processing.

There were 9 developer solution variables tested. Density shifts of 2 steps occurred with 3 of the conditions tested. All other developer solution variables showed step density shifts of less than 2 steps. The 3 conditions with 2-step density shifts were developer dilution with automatic or manual film processing and developer aging with automatic processing. Both automatic and manual developer solution concentrations required an 85% change to produce a 2-step density shift; this is a large amount of change necessary to

degrade diagnostic quality by approximately 25% of the clinically acceptable density range. For developer solution aging in the automatic processor, a 2-step density shift occurred after 20 days. Less solution degradation with aging occurred with manual film processing. This can be due to higher developer temperatures and a larger surface to volume ratio in the automatic processor.

Less than 2 but 1 or more step density shifts occurred with development time changes and developer aging with manual film processing within the experimental conditions tested. Thus, there is a wide range of changes in these 2 film processing factors that must occur before clinical diagnostic quality is degraded by approximately 12.5% of the available 7-8 step density range.

Less than 1 but 1/2 or more step density shifts occurred with developer solution temperature and chemical depletion with manual film processing within the experimental range tested. Thus, a large range of change must occur in these 2 film processing variables before clinical diagnostic radiographic quality is degraded by approximately 6.25% of the available step density range.

Developer solutions appear to be capable of processing a great number of films. This study demonstrated that 25,650 films could be processed in a fresh 5-gallon developer solution when processed in a very short time span. Chemical degradation from processing this number of films caused a 1/2-step density shift, or a change of approximately 6.25%

of the clinically acceptable density range. This is far in excess of the number of films observed or implied by other investigators. Two articles by the Kodak Company (Dental Radiography and Photography 1928, 1930) stated that 9,600 or 8,750 dental films could be processed through 5 gallons of developer solution with no time element being expressed, but everyday use over an intended time period was implied. Brown et al. (1973) found that 6,965 fully exposed dental films could be processed in 5 gallons of developer solution over a 125-day time period before degradation of the developer solution was first noticed. They stated that if oxidation did occur over this time period, the solutions were not affected, and implied that the solution degradation was due only to the 6,965 processed dental films. When chemical depletion and aging are measured separately, as in this study, it appears from Figures 11 and 12 that developer chemical depletion from processing more than the number of films stated by Kodak and Brown et al. caused little solution degradation, while developer solution degradation due to aging alone produced density changes similar to those found by Brown et al. It is thus possible that Brown and associates' observations were due more to aging than to developer solution chemical depletion.

In monitoring film processing variations the test object detected changes similar to changes detected by the sensitometer. Table 2 shows density change over the range tested for each variable of the 10 mm-step of the test object

and step 9 of the optical wedge of the sensitometer. The performances of both test systems are similar as indicated by the small differences between the changes reflected by each of the 2 detection methods. These differences averaged 0.09 density regardless of which system was used. The clinically acceptable density range is 7-8 step densities, or a density range of 2.1. The average density difference between the test object and the sensitometer (0.09) is 4.3% of the clinically acceptable density range, which indicates that there is a relatively small difference in the 2 systems.

Polanski and Smith (1968) stated that non-screen film exposed to x-rays were almost useless in processing control, and that freshly produced sensitometer strips exposed and processed daily were the most accurate guides for density control. Use of the sensitometer has long been recognized as the most accurate method of monitoring film processing and has been the standard used by numerous investigators in quality control. The sensitometer used in this study is one such instrument. Table 2 shows that there was little difference between the sensitometer and the test object. These results appear to be inconsistent with the conclusions of Polanski and Smith. A possible explanation for the apparent discrepancy is that the objective of Polanski and Smith was to detect very small changes in automatic processing with the greatest degree of accuracy. The objective of the step-wedge test is to detect much larger processing changes, although small relative to the clinically acceptable density

Table 2

A summary of density changes by sensitometer and test object over the range of each processing variable tested.

Processing Variable and Range Tested	Density Changes Over Tested Range of Variable		
	10 mm Step of Test	Step 9 of Sensi- tometer	Density Differ- ence Between Test Object and Sensitometer
MANUAL PROCESSING			
Developer Dilution 100% to 10% conc.	0.55	0.58	0.03
Development Time 1-8 minutes	0.68	0.73	0.05
Development Temp. 60°F to 83°F	0.37	0.42	0.05
Developer Aging 0-90 days	0.24	0.00	0.24
Developer Chemical Depletion 0-25,600 films (5 gal)	0.15	0.28	0.13
Fixer Dilution* 100% to 10% conc.	0.01	0.04	0.05
Fixing Time* 1/2 to 10 minutes	0.01	0.00	0.01
Fixing Temp. 60°F to 83°F	0.03	0.01	0.02
Fixer Aging 0-90 days	0.04	0.05	0.01
AUTOMATIC PROCESSING			
Developer Dilution 100% to 10% conc.	0.53	0.61	0.08
Development Temp. 60°F to 86°F	0.26	0.61	0.35
Developer Aging 0-30 days	0.88	0.70	0.18
Developer Chemical Depletion 0-2,820 films (2 qts)	0.07	0.15	0.22
Fixer Dilution* 100% to 10% conc.	0.06	0.03	0.00
Fixer Temperature 60°F to 86°F*	0.03	0.03	0.00
Fixer Aging 0-30 days	0.04	0.00	0.04
			0.09
			<u>Average</u>

*Data prior to films becoming unfixed

range dentists will accept. Polanski and Smith did not relate the magnitude of processing changes they wished to detect to the clinical situation. Table 2 shows that while the sensitometer is more accurate in detecting film processing changes, the difference between it and the test object is only 4.3% of the clinically acceptable density range and, thus, there is a relatively small difference between the 2 detection systems.

Visual Matching

The usefulness of the stepwedge test in dental quality control depends, in part, upon visual matching of similar step densities. The test object reflects film processing changes with an accuracy similar to the sensitometer. Though extraction of information is most accurately accomplished with a densitometer, visual detection is much more simple, inexpensive, and less time consuming. Visual detection can replace the densitometer since the visual error of the stepwedge test method is small relative to the clinically acceptable density range. The ability of dental auxiliaries to match correctly similar step densities is good, since none of the 30 readers in 270 responses mismatched similar step densities by more than 1 step. The stepwedge test uses visual detection of a 2-step density change of a single step, measured on a reference radiograph, to detect x-ray machine or processing changes in need of correction.

Thus, the maximum error is small in relation to the available 7-8 step densities of the clinically acceptable density range.

Figure 7 shows that visual matching of whole step densities, equal to or darker than a single step on the reference radiograph, resulted in a great increase in accuracy. Reference films and test films exposed 1 step density darker than the reference film used in this study would allow the operator to take advantage of these areas of increased accuracy. The accuracy of visually matching similar step densities could, therefore, possibly be increased.

Summary

It has been shown that changes in all x-ray machine and film processing variables tested in this study are accurately reflected by the test object, and if measured with the densitometer, are very similar to the light exposed test strips from the sensitometer, while visual detection of these changes is less accurate. However, the manner in which the stepwedge test is used clinically to detect only large changes allows its effective clinical use instead of densitometric detection. It was shown that the visual ability of dental auxiliaries to match similar step densities is quite good. Since the clinically acceptable density range is very large the test is useful, because it detects changes before diagnostic information is lost. The amount of latent

image fading, over the time that test films would reasonably be expected to be used, is very small, thus the stepwedge test should perform effectively between processing solution changes in dental offices. The stepwedge test uses inexpensive materials and little operator time, and needs little operator training compared to other commonly used or recommended quality assurance systems. The results of this study were based upon tests of each variable independently. No attempt was made to determine the effects of possible combinations of variables or possible additive effects of variables. These effects should be investigated in future studies. Future studies could also determine the feasibility of narrowing the range of detection by using a 1-step density shift of a particular step instead of a 2-step shift, or by doubling the number of steps on the test object. The effectiveness of the test object for use with dental screen film needs to be investigated. The stepwedge test is an effective, inexpensive, and simple quality assurance test that will detect single occurring x-ray machine and film processing deficiencies prior to the loss of clinical diagnostic quality for both manual and automatic processing of intraoral films.

CONCLUSIONS

1. The density range of the 8-step test object is 2.5.
2. The clinically acceptable density range that many dentists accept is 2.1, or 7-8 step densities of the test object.
3. A 2-step density change of a single step, as measured on a reference radiograph, is a detection level of approximately 25% of the clinically acceptable range.
4. A wide variation in x-ray machine or film processing must occur before a 2-step density shift is produced.
5. The amount of latent image fading of Kodak DF-58 dental film is extremely small, if any, over a 90-day period when films are properly stored.
6. The stepwedge test does not detect small fixer solution changes affecting film clearing for manual or automatic film processing.
7. Developer solution depletion with aging is greater with automatic than manual film processing.
8. Developer solutions for manual and automatic film processing are capable of processing a very large number of dental films when processed in a short time period.

9. Developer solution aging is a greater source of solution degradation than the number of films processed.
10. A 15 kVp variation produces a 2-step density change, and densitometer measurement is needed if the detection of small kVp changes is desired.
11. With the GE-1000 x-ray machine, an increase of 5 mA without a corresponding kVp increase does not change the x-ray energy output and is not detected by the stepwedge test.
12. In monitoring manual or automatic film processing variations, the stepwedge test detected changes with a similar degree of accuracy as the sensitometric method.
13. The use of non-screen intraoral dental films with the test object can be useful in clinical dental radiographic quality control, and can be used instead of the sensitometer.
14. The error in visually matching similar step densities is ± 1 step, and visual detection of density changes can be used instead of a densitometer in clinical dental radiographic quality control.
15. Under the conditions tested in this study, the stepwedge test is an effective, inexpensive, and simple quality assurance test that will detect single occurring x-ray machine or film processing deficiencies prior to the loss of clinical diagnostic radiographic quality for both manual and automatic processing of intraoral films.

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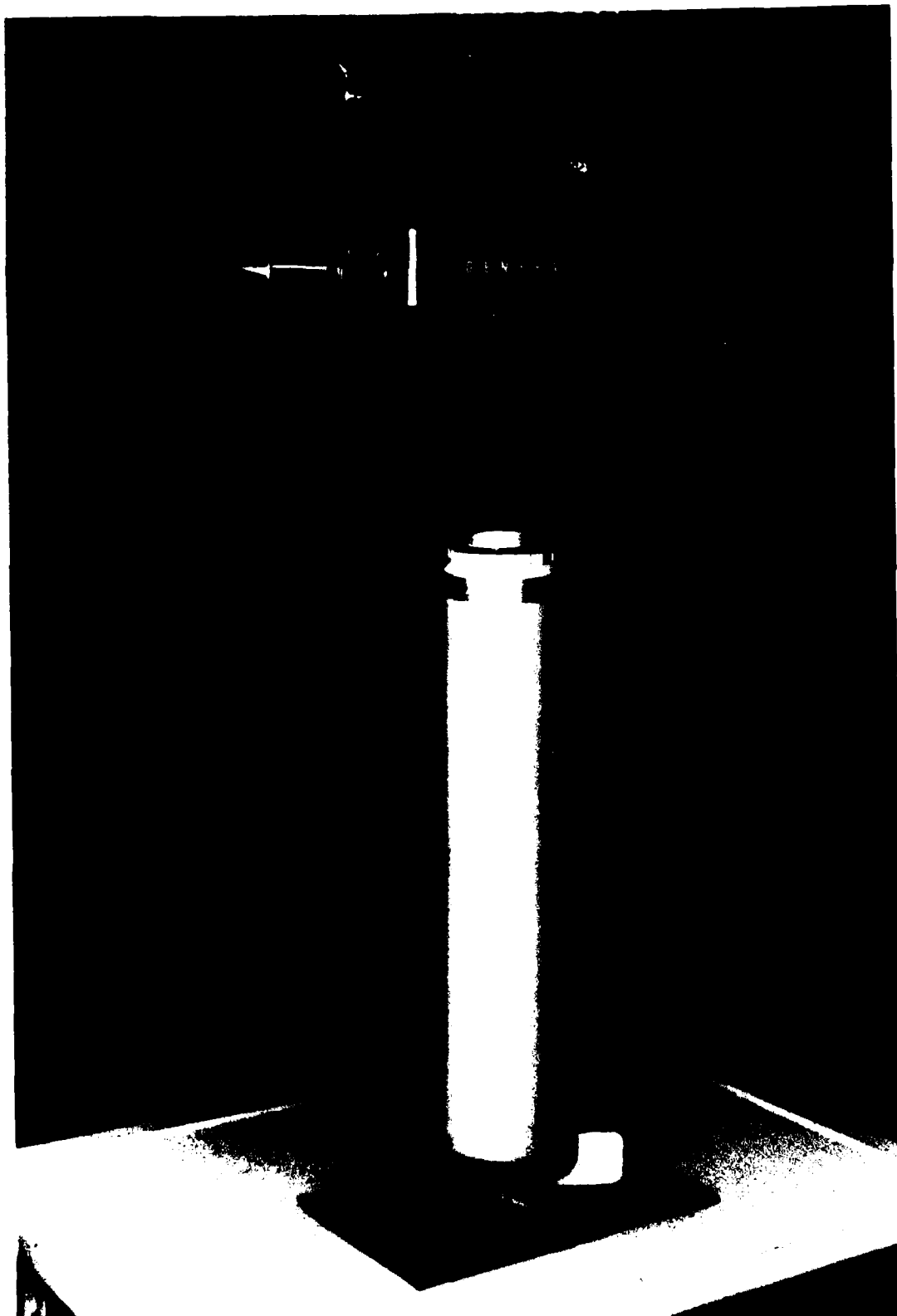
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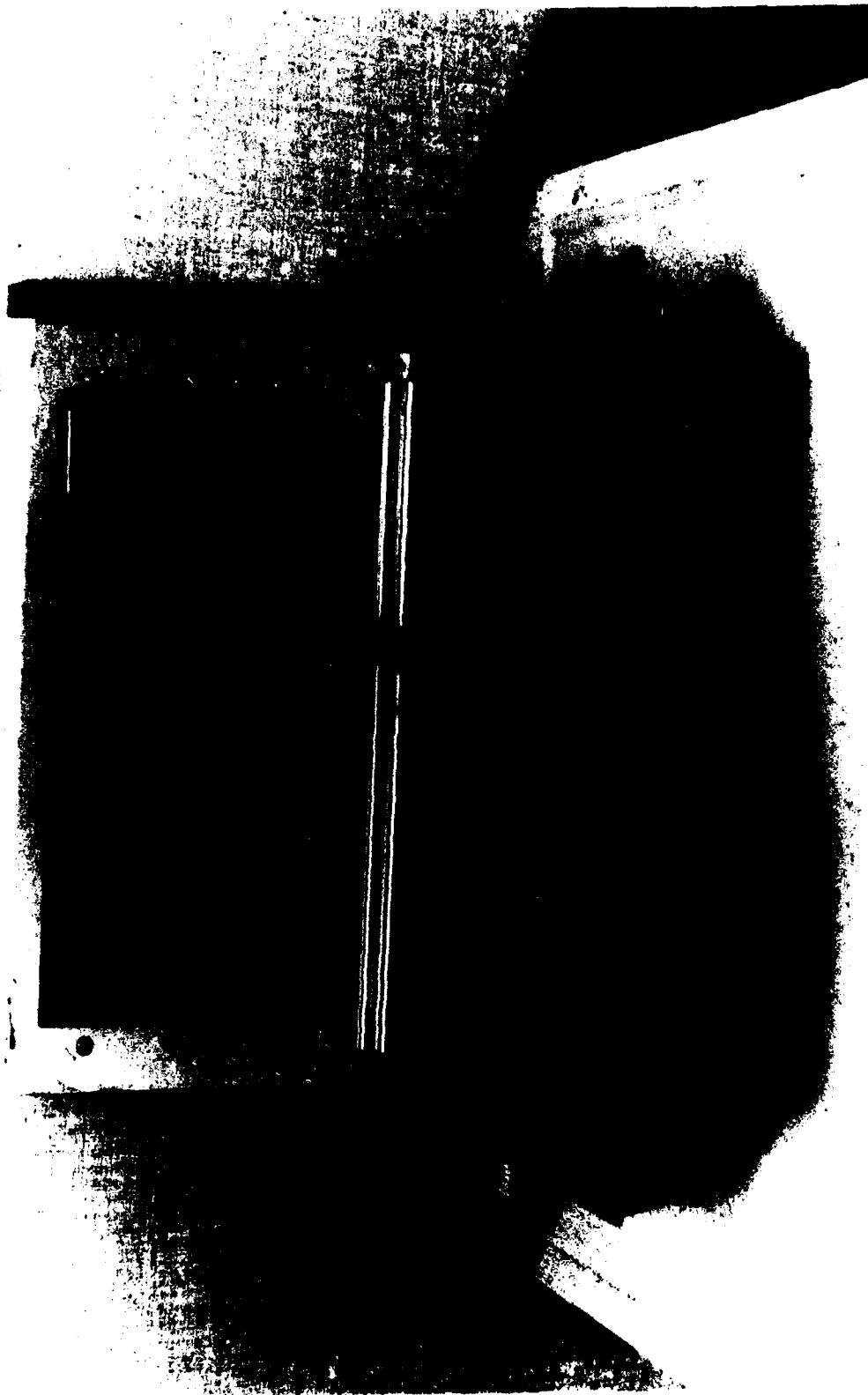
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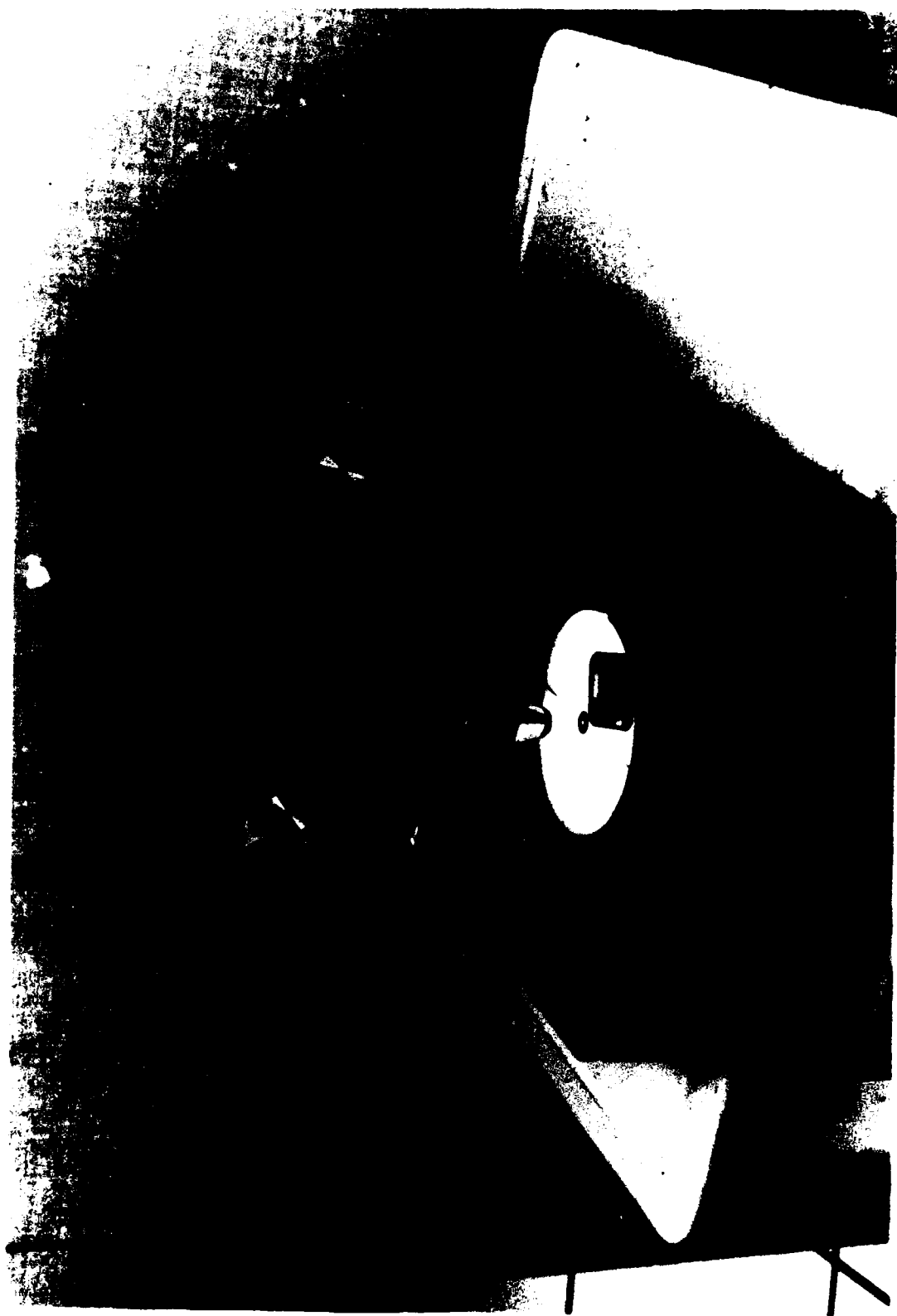


Figure 3
Macbeth model TD502 densitometer and a periplapical
radiograph of the test object

